LAKE SHAKAMAK FEASIBILITY STUDY AND MANAGEMENT PLAN

Prepared for: Division of State Parks
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Disclaimer

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SUMMARY

Shakamak State Park is noted for its three lakes - Lake Shakamak constructed in 1930, Lake Lenape constructed in 1934, and Lake Kickapoo constructed in 1965. Although the lakes' drainage basins are largely forested, sediments and nutrients from substantial areas of agriculture have reached the lakes over the years.

Of the three, Lake Shakamak is the most eutrophic. Nearly 50% of the lake's surface area is covered by rooted aquatic macrophytes and the lake suffers from seasonal algal blooms and significant dissolved oxygen depletion in the hypolimnion. Along with this excessive plant production, Lake Shakamak also supports an abundant fish community dominated by large bluegills and redear sunfish.

Watershed modelling suggests that slope and distance from the lake are important factors affecting the transport of sediments and nutrients to the lake. Currently, external loading of phosphorus from the watershed alone is significant enough to produce eutrophic conditions. However, internal recycling of phosphorus from the sediments during extended periods of hypolimnetic anoxia contributes the largest amount of phosphorus to the water during the growing season, about 95% of total phosphorus loading. Sediment delivery to the lake has been limited greatly by extensive aquatic macrophyte stands at the mouths of each inlet and by a series of culverts and check dams which are now largely full and inoperative.

The proposed management plan for Lake Shakamak includes the implementation of best management practices (BMPs) whenever possible in the watershed and the cleaning and repair of check dams and culverts. Both of these approaches work to reduce the loading of sediments and phosphorus to the lake. However, watershed management activities along are insufficient to bring about a timely improvement in Lake Shakamak's water quality.

In-lake management practices for Lake Shakamak are recommended to speed the lake's recovery. The most important in-lake practice proposed is a hypolimnetic application of aluminum sulfate (alum) to precipitate soluble phosphorus and inactivate the release of phosphorus from the sediments. Such a treatment can provide 5-10 years of control. Selective mechanical harvesting of rooted macrophytes is also recommended to clear areas around piers, boat launches, and the beach, provide access to the cabins, and to create fishing lanes.

Lake Lenape's water quality is only marginally better than Lake Shakamak's. The implementation of watershed BMPs is recommended to reduce sediment and nutrient loadings to Lake Lenape. A sedimentation basin and constructed wetland on the lake's inlet may also be warranted. The most effective management activity for maintaining Lake Kickapoo's high water quality is the successful management of Lakes Shakamak and Lenape, which drain directly into Lake Kickapoo.

1.0 INTRODUCTION

In 1980 the Indiana Department of Natural Resources Division of State Parks undertook a system-wide evaluation of its services. The resulting State Parks System Plan recommended master plan revisions for each of the parks to bring Indiana's park plans up-to-date. During 1985-1986, the Shakamak State Park Master Plan was prepared by the Division of Outdoor Recreation and the Division of State Parks. Key features of the plan include:

- Closing the existing beach due to deteriorating water quality in the lake.
- Construction of a swimming pool.
- Construction of 20 new cabins, in phases, on a peninsula across the lake from the existing 29 cabins.
- Commissioning a study to determine more specifically what is affecting the water quality in Lake Shakamak.

In March 1988, the Division of State Parks contracted with the Environmental Systems Application Center (ESAC) at Indiana University's School of Public and Environmental Affairs (SPEA) to conduct a study of Lake Shakamak. The study was to diagnose the water quality and sedimentation problems at the lake and prepare a management plan to address the problems identified. The Division of State Parks also requested that ESAC monitor water quality at Lake Lenape and Lake Kickapoo during the course of the study. This report documents the results of these studies.

2.0 LAKE SETTING

2.1 LOCATION

Shakamak State Park covers 1,766 acres of rolling land in Clay, Greene and Sullivan counties in southwest Indiana (Figure 1). Access to the park is from State Road 48 one mile west of the town of Jasonville. The park is noted for its three lakes, Shakamak, Lenape, and Kickapoo, which are popular for fishing and boating. A swimming beach, campground, horse stables, and cabins are the principal recreational development. (Indiana Dept. Natural Resources, 1986).

2.2 LAKE MORPHOMETRY

Morphometric parameters (e.g. depth, area, volume, etc.) are very useful in understanding physical relationships in lakes. Often, a lake's morphometry provides insights into biological and chemical processes that may take place in the lake.

2.2.1 Lake Shakamak

Lake Shakamak was built in 1930. It uses an old railroad grade as the base of its dam, which spans Big Branch Creek. The lake is 23 hectares (56 acres) in size with a maximum depth of 7.9 meters (26 feet) and a volume of $7.5 \times 10^5\ m^3$ (608 acre feet) (Dept. Natural Resources, 1986). Morphometric features of Lake Shakamak are presented along with those of lakes Lenape and Kickapoo in Table 1.

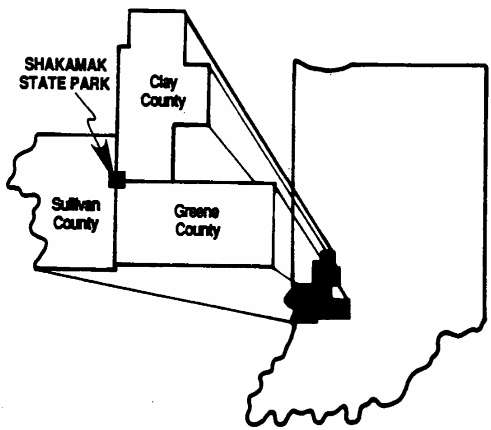

Figure 1. Shakamak State Park location map.

TABLE 1. Morphometric Parameters

LAKE	AREA hectares (acres)	VOLUME m^3 (acre-feet)	AVE. DEPTH meters (feet)	MAX. DEPTH meters (feet)
Shakamak	23 (56)	750,000 (608)	3.3 (11)	7.9 (26)
Lenape	20 (49)	604,000 (490)	3.0 (10)	8.8 (29)
Kickapoo	117 (290)	8,800,000 (7,150)	7.6 (25)	13.4 (44)

Source: Dept. of Natural Resources (1986)

Because of its irregular, glove-like shape, Lake Shakamak has a rather high shoreline development value of 3.74. Shoreline development (D_L is the ratio of the length of the shoreline (L) to the circumference of a circle of equal area (A) to that of the lake.

$$D_L = \frac{L}{2\sqrt{\pi A}}$$

A lake with a perfect circular shape has a shoreline development value of 1.0.

The high shoreline development value for Lake Shakamak is of considerable interest because it reflects the potential for greater development of littoral communities in proportion to the area of the lake. Littoral communities occupy the shallow areas where rooted macrophytes (plants) can grow and are the communities of greatest primary production in lakes. At Lake Shakamak, this is the area from 0 to 3 meters in depth. Approximately 50% of the lake's surface area is within the littoral zone (Figure 2). Figure 2 is a hypsographic curve which graphically represents the relationship between the surface area of Lake Shakamak and its depth. From this, it is seen that the area of the lake between 0 and 10 feet is approximately 120,000 m^3 or about one-half of the lake's total surface area of 230,000m^3.

Thus, on the basis of the shoreline development value, one might expect that Lake Shakamak could support a large macrophyte community. The high shoreline development value also suggests that the lake could be influenced more greatly by shoreline activities, such as erosion and runoff.

Another curve, comparing Lake Shakamak's depth with its volume is presented in Figure 3. This depth-volume curve is useful in examining a number of important lake features.

1. The reduction in volume for a given drop in water level due, for example, to drought or drawdown.

2. The percent of total lake volume in which photosynthesis occurs.

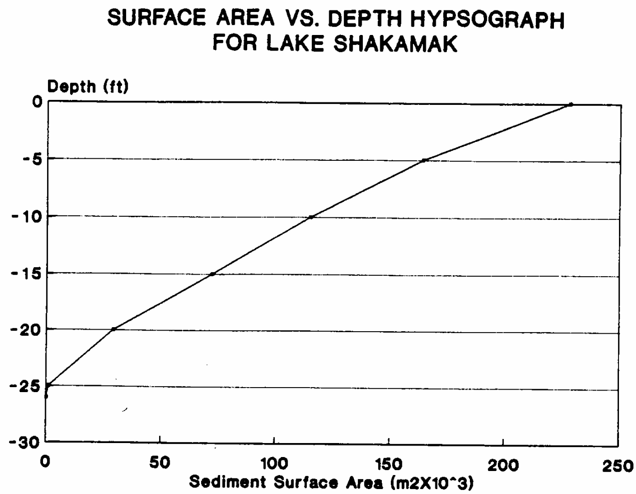

Figure 2. Hypsograph (depth-area curve) for Lake Shakamak.

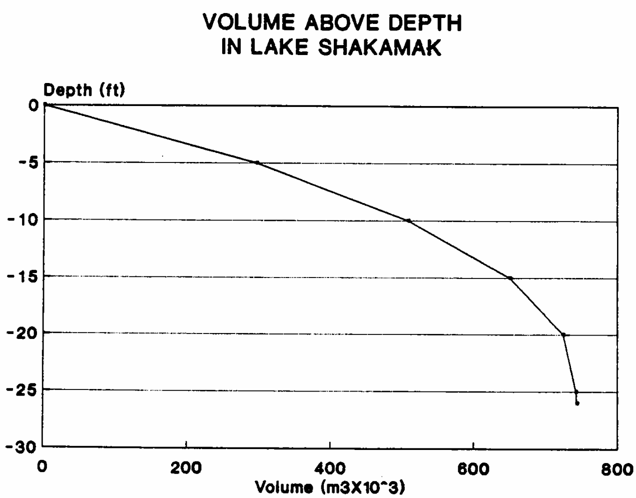

Figure 3. Depth-volume curve for Lake Shakamak.

3. The percent of lake volume in the hypolimnion or epilimnion and from this, the percent of lake volume which is anoxic during summer stratification, etc.

These curves will be referred to later in the report as we discuss the water quality data collected and explore management options.

2.2.2 Lake Lenape

Lake Lenape was built in 1934 and was originally called Lake Jason. In 1965, the Lenape dam was increased in height and Lenape was enlarged from its initial 14.5 ha (36 acres) to its present 20 ha (49 acres) (Department of Natural Resources, 1986). Lake Lenape was a maximum depth of 8.8 meters (29 ft.) and contains 6.04 10^5 m^3 (490 acre feet) of water (Table 1).

2.2.3 Lake Kickapoo

The construction of Lake Kickapoo was funded under Public Law 566 as part of the flood control measures for the Busseron Creek watershed. The project was completed in 1965. Lake Kickapoo is 117 ha (290 acres) in size with a maximum depth of 13.4 meters (43 feet) and a volume of 8.8 X 10^6 m^3 (7,150 acre feet). It is the deepest and largest of the three lakes. Lake Shakamak and Lenape drain directly into Lake Kickapoo.

All three lakes are maintained at the same elevation of 550 feet MSL by culverts which hydrologically connect the lakes. Gates at lakes Shakamak and Lenape allow them to be maintained at 550 feet if Lake Kickapoo is drawn down.

2.3 WATERSHED CHARACTERISTICS

2.3.1 Size

The watershed feeding Lake Kickapoo is approximately 1,239 ha (3,062 acres) in size. Of this, 405 ha (1,000 acres) drains through Lake Shakamak, 468 ha (1,155 acres) through Lake Lenape, and the remaining 367 ha (907 acres) drains directly into Lake Kickapoo (Figure 4). The watershed area to lake surface ratio is 17.1:1 for Lake Shakamak. A ratio of 7:1 is usually sufficient to provide an adequate water flushing rate through lakes, however, the actual amount of water yield to lakes is a function of slope, soil type, vegetation cover and other factors (see Section 6.2). The watershed area to lake area ratios for lakes Lenape and Kickapoo are 23.6:1 and 10.6:1 respectively.

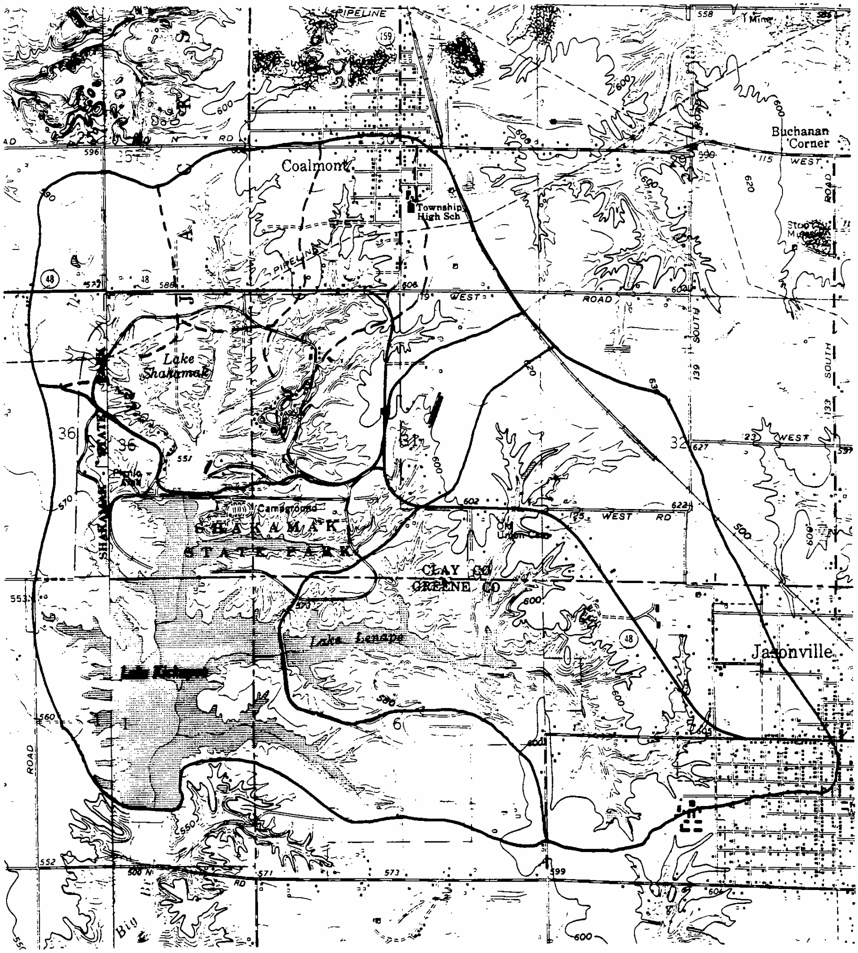

Figure 4. Watershed map. Lake watershed boundaries are shown with bold line; Shakamak sub-watersheds shown with dashed line.

2.3.2 Topography

Most of the overall watershed is relatively flat upland. Elevations range from 510 feet MSL at the bottom of Big Branch Creek to 630 feet MSL on the upland area along the northeast edge of Lake Lenape's watershed. Areas of steep slopes occur primarily along valleys of the streams feeding the lakes.

2.3.3 Geology

Shakamak State Park lies within the Wabash Lowland physiographic province, an area of gently rolling hills and flat river valleys and bottomlands (ESAC, 1983). Within this lowland, rocks of the Pennsylvanian System, which include coal, form the bedrock (Figure 5). The bedrock also includes layers of shale, sandstone, clay, limestone and conglomerate (Department of Natural Resources, 1986). The coal deposits are in several narrow bands generally one to two meters thick. The Seeleyville III vein approximately 200 feet below the surface was mined by two underground mines in the park between 1903 and 1910. Several surface mines currently work shallower coal deposits in areas around the park, however no active mining takes place within the lakes' watersheds.

2.3.4 Soils

There are five soil types within the Lake Shakamak watershed; Ava, Cincinnati, Hickory, Stendal, and Vigo silt loams (Table 2). These are broken down into fourteen categories based on slope and erosivity. The Vigo silt loams dominate the watershed (almost 54%). These are typically in upland areas with agricultural land uses. Vigo silt loams have low permeabilities and are susceptible to soil erosion during storm events.

TABLE 2. Lake Shakamak Watershed Soils.

Soil Name	ID	Slope	Comment	Area (m2)	% Area
Ava silt loam	AIB2	2-6%	eroded	667,600	19.2
Ava silt loam	AIB3	2-6%	severely eroded	4,000	0.1
Cincinnati silt loam	CnB2	2-6%	eroded	54,400	1.6
Cincinnati silt loam	CnC2	6-12%	eroded	6,000	0.2
Cincinnati silt loam	CnC3	6-12%	severely eroded	44,000	1.3
Cincinnati silt loam	CnD3	12-18%	severely eroded	52,000	1.5
Hickory silt loam	HcD	12-18%		76,000	2.2
Hickory silt loam	HcE	18-25%		70,400	2.0
Hickory silt loam	HcF	25-35%		314,400	9.1
Hickory silt loam	HcF3	18-35%	severely eroded	47,200	1.4
Hickory silt loam	HcG	35-50%		108,400	3.1
Stendal silt loam	Sn	0-2%	frequently flooded	165,200	4.8
Vigo silt loam	VgA	0-2%		1,735,200	50.0
Vigo silt loam	VgB2	2-4%	eroded	128,000	3.7

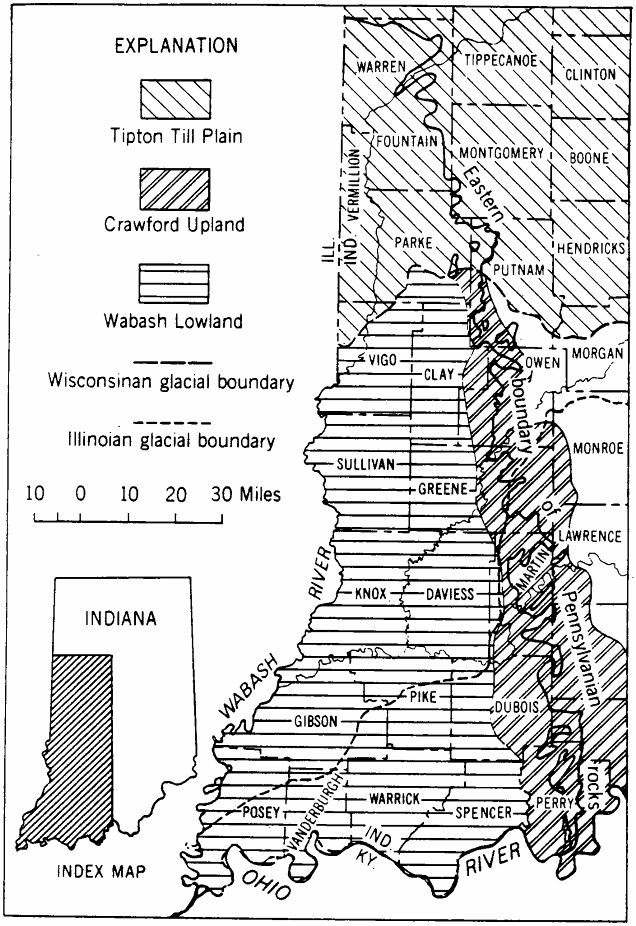

Figure 5. Geological map of Shakamak State Park and area.

Almost 29% of the soils in the watershed are eroded or severely eroded. Generally these soils are on the steeper slopes along the lake edge or the tributaries. Within the park, these soils are typically stabilized by forest cover. Disruptions due to construction activities within the park are possible causes of soil erosion and ultimately sedimentation in the lake.

2.4 LAND USE

Land uses within the watersheds of lakes Shakamak, Lenape and Kickapoo are presented in Table 3. Of the three lakes, Lenape has the greatest percentage of its watershed in agricultural land use. One would expect greater soil erosion from agricultural lands than from any other land use. The highest runoff rates, on the other hand, are usually from the residential or commercial land use categories as these include roads, parking lots and other paved or impermeable surfaces. How these factors affect sediment and runoff delivery to Lake Shakamak is discussed further in Section 6.2.

TABLE 3. Land Uses in Each Lake's Watershed

Land Use	SHAKAMAK Acres(ha)		%	LENAPE Acres(ha)		%	KICKAPOO[1] Acres(ha)		%
Commercial	4	(2)	0.4	1	(<1)	0.1	10	(4)	0.3
Residential	73	(29)	7.3	82	(33)	7.1	162	(65)	5.3
Agricultural	366	(148)	36.6	531	(215)	45.9	1019	(413)	33.3
Pasture	0	0	0	42	(17)	3.7	215	(87)	7.0
Forest	489	(198)	48.8	436	(177)	37.7	1289	(522)	42.1
Stream	10	(4)	1.0	15	(6)	1.3	33	(13)	1.1
Lake	59	(24)	5.9	49	(20)	4.2	335	(135)	10.9
TOTALS	1001	(405)	100.0	1156	(468)	100.0	3063	(1239)	100.0

[1]Total watershed area including lakes Shakamak and Lenape.

3.0 WATER QUALITY

3.1 METHODS

Water quality samples were collected from Lake Shakamak on a monthly basis from April through October, 1988 and from lakes Lenape and Kickapoo bi-monthly over the same period. Sample collection sites were located over the deepest water at each lake. These locations are indicated on Figure 4. At each site, water samples were collected from the epilimnion at 0.5 meters below the surface and from the hypolimnion at 1.0 meter above the bottom. Dissolved oxygen and temperature measurements were made at one meter depth intervals.

Water quality parameters included in the sampling program and the analytical methods used are listed in Table 4. Replicate samples were analyzed for all parameters not measured in situ. Field and/or laboratory blanks were collected to insure quality control.

3.2 RESULTS

3.2.1 Lake Shakamak

Temperature and Dissolved Oxygen

Dissolved oxygen (DO) and temperature data and profiles for Lake Shakamak on each sampling data are given in Figures 6(a) - 6(g). On April 8 the lake was well-mixed down to 5 meters but by May 17 the mixing zone (epilimnion) is no deeper than 2-3 meters. The Relative Thermal Resistance to Mixing (RTRM) has a maximum value at 3 meters. This is the depth interval at which temperature changes the most and is referred to as the thermocline.

These water temperature differences create a density gradient which effectively isolates the deeper waters (hypolimnion) below the thermocline from the epilimnion. Without contact with the air-water interface, the hypolimnetic waters are not reaerated by diffusion and the water is too dark for photosynthesis to occur, thus no new DO is produced in the hypolimnion during stratification. Furthermore, existing DO in the hypolimnion is consumed during bacterial decomposition of organic matter and by the oxidation of chemical compounds, for example the oxidation of ammonia (NH_4^+) to nitrate (NO_3^-). Therefore, it is common for the hypolimnions of lakes having significant organic matter in the sediments to have reduced DO concentrations during stratification.

TABLE 4. Analytical Methods and Quality Control Procedures

Parameter	Method	Blanks	Replicates	Source
Temperature	YSI S4A Meter	-	-	-
Dissolved Oxygen	YSI S4A Meter	-	-	-
pH	Corning	-	-	-
Conductivity	YSI Meter	-	-	-
Total Phosphorus	Sulfuric acid/nitric acid digestion. Ascorbic acid method.	Lab & field	2	APHA (1985)
Soluble Reactive Phosphorus	Ascorbic acid method	Field	2	APHA (1985)
Nitrate-Nitrogen	Electrode method	Field	2	APHA (1985)
Ammonia Nitrogen	Electrode method	Field	2	APHA (1985)
Alkalinity	Titrametric to pH 4.3 endpoint	Lab & field	2	APHA (1985)

In Lake Shakamak, these processes combine to yield an anoxic hypolimnion of considerable size (Figure 7). Following spring overturn in early April, the thickness of the anoxic zone increases until mid-July when it reaches a maximum thickness of four meters. At this time, only the upper three meters of Lake Shakamak contain measurable DO. Since fish can become stressed at DO concentrations below 3 mg/l, only the upper two meters of Lake Shakamak (53% of the lake's volume) could support fish in mid-July. At fall overturn in October, this large mass of anoxic water is mixed in with the remaining lake water, causing a drop in overall DO concentration throughout the water column to approximately 3 mg/l, the stress limit for many fish.

The magnitude of the anoxic zone in Lake Shakamak suggests that the lake contains a significant quantity of undecomposed organic material. This can be from decaying plants (algae and macrophytes) from previous years that have accumulated in the sediments or from decay of the present year's plankton growth as the dead cells sink through the water column. This sinking process is often referred to as 'plankton rain.'

LAKE SHAKAMAK
April 8, 1988
STATION 1

SECCHI DEPTH .74 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	13.2	12.2	117	0
1.0	13.0	12.4	120	3
2.0	13.0	12.1	116	0
3.0	12.8	10.4	96	3
4.0	12.8	8.1	71	0
5.0	11.9	7.1	61	13
6.0	8.5	6.0	50	38
7.0	7.0	0.5	4	11

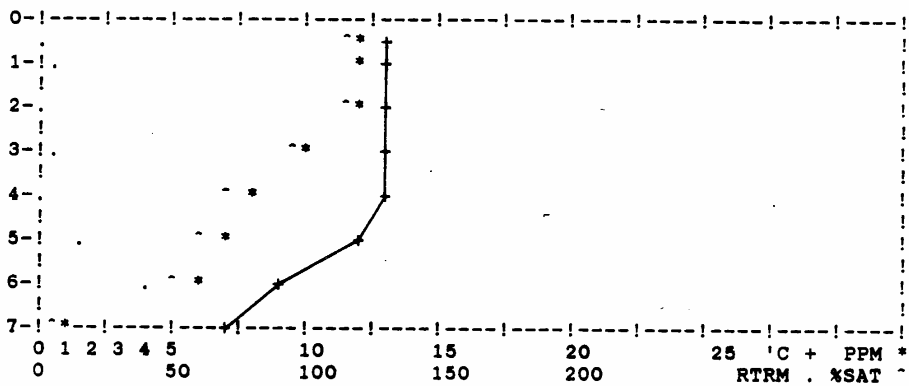

Figure 6(a). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 4-8-88.

LAKE SHAKAMAK
May 17, 1988
STATION 1

SECCHI DEPTH 2.2 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	21.7	8.9	79	0
1.0	21.5	9.2	83	5
2.0	21.5	9.6	87	0
3.0	18.0	7.8	68	88
4.0	14.5	3.0	23	71
5.0	11.1	0.6	4	52
6.0	9.0	0.3	2	23
7.0	8.0	0.2	1	8

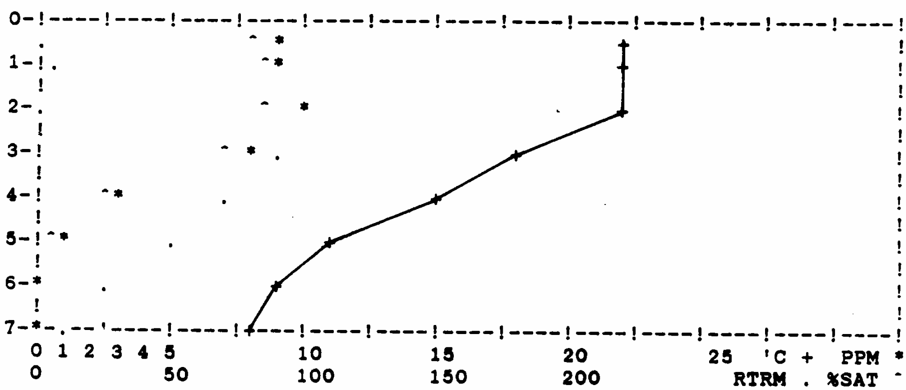

Figure 6(b). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 5-17-88.

LAKE SHAKAMAK
June 16, 1988
STATION 1

SECCHI DEPTH 2.0 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	26.0	9.4	85	0
1.0	26.0	9.2	83	0
2.0	22.5	8.1	71	107
3.0	18.0	0.1	1	116
4.0	13.8	0.1	1	83
5.0	11.0	0.1	1	41
6.0	9.0	0.1	1	22

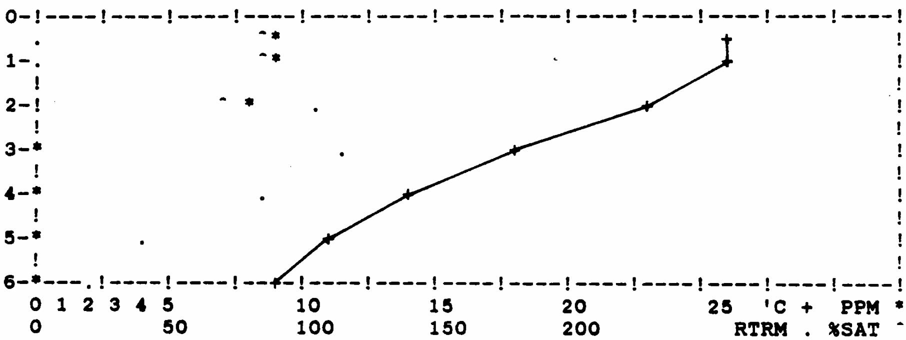

Figure 6(c). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 6-16-88.

LAKE SHAKAMAK
July 14, 1988 SECCHI DEPTH 1.3 METERS
STATION 1

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	29.0	10.7	100	0
1.0	28.0	10.4	96	36
2.0	26.5	3.0	23	51
3.0	22.0	0.1	1	138
4.0	15.0	0.1	1	164
5.0	12.3	0.1	1	45

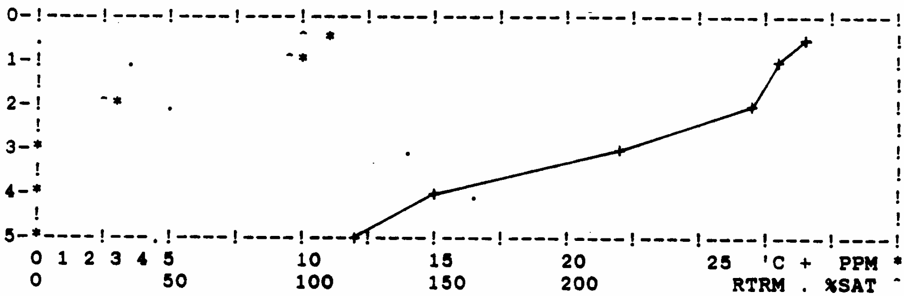

Figure 6(d). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 7-14-88.

LAKE SHAKAMAK
August 10, 1988
STATION 1

SECCHI DEPTH 2.4 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	30.0	9.8	89	0
1.0	30.0	9.3	84	0
2.0	29.0	7.1	61	37
3.0	24.8	0.1	1	142
4.0	18.0	0.1	1	185
5.0	13.5	0.1	1	88
6.0	12.5	0.1	1	16

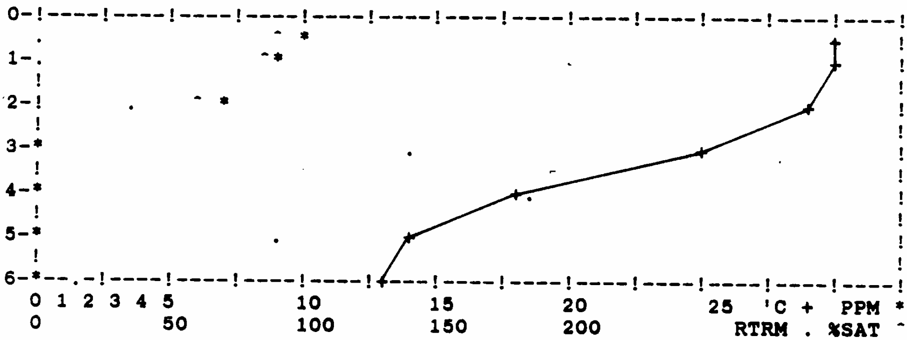

Figure 6(e). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 8-10-88.

LAKE Shakamak
September 20, 1988
STATION 1

SECCHI DEPTH .99 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	21.8	5.7	47	0
1.0	21.5	5.5	45	8
2.0	21.0	4.8	39	14
3.0	19.0	0.2	1	51
4.0	18.0	0.2	1	23
5.0	13.0	0.2	1	96
6.0	11.0	0.1	1	28

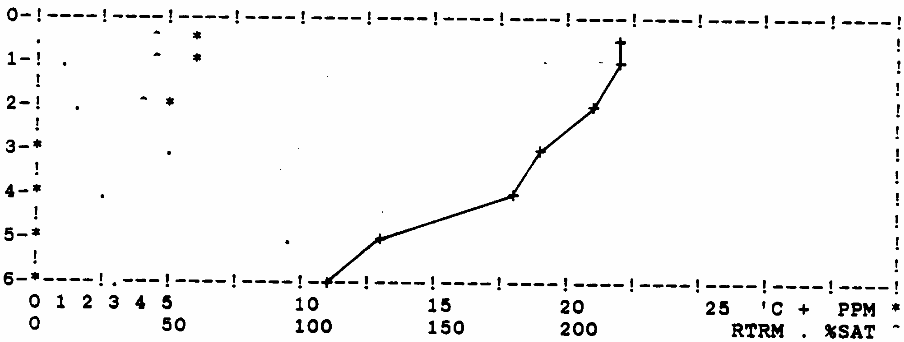

Figure 6(f). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 9-20-88.

LAKE SHAKAMAK
October 25, 1988
STATION 1

SECCHI DEPTH 3.9 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	12.0	3.0	23	0
1.0	12.0	2.9	22	0
2.0	12.0	2.5	19	0
3.0	12.0	3.2	25	0
4.0	12.0	2.9	22	0
5.0	12.0	2.7	21	0
6.0	12.0	2.7	21	0

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0-!----!----!----!----!----!----!----!----!----!----!----!----!----!
  .    -*                 +                                        !
1-.   - *                 +                                        !
  !                                                                !
2-.   - *                 +                                        !
  !                                                                !
3-.    -*                 +                                        !
  !                                                                !
4-.   - *                 +                                        !
  !                                                                !
5-.   - *                 +                                        !
  !                                                                !
6-.----!*---!----!----!---+!----!----!----!----!----!----!----!----!
  0 1 2 3 4 5         10        15        20         25  'C + PPM *
  0         50        100       150       200         RTRM . %SAT -
```

Figure 6(g). Temperature (+) and dissolved oxygen (*) profiles for Lake Shakamak on 10-25-88.

As DO in hypolimnetic waters approaches zero and anoxic conditions appear, redox potential decreases rapidly. This results in a chemically reducing environment with high electron activity. Reducing conditions promote many changes in the hypolimnion, especially at the sediment-water interface. For example, iron (Fe^{+++}) in ferric phosphate ($FePO_4$) is reduced to ferrous iron (Fe^{++}) which liberates phosphate ion ($PO_4^{\equiv}$) according to the following reaction.

$$FePO_4 + e^- \rightarrow Fe^{++} + PO_4^{\equiv})$$

This internal release of soluble phosphorus from the sediments can be a significant source of nutrients for phytoplankton. A reducing environment can also cause increases in bases (alkalinity), ammonia (NH_4^+), and other dissolved ions.

In summary then, low DO concentrations are not only detrimental to fish and other aquatic life, but they can also produce undesirable changes in a lake's chemical environment.

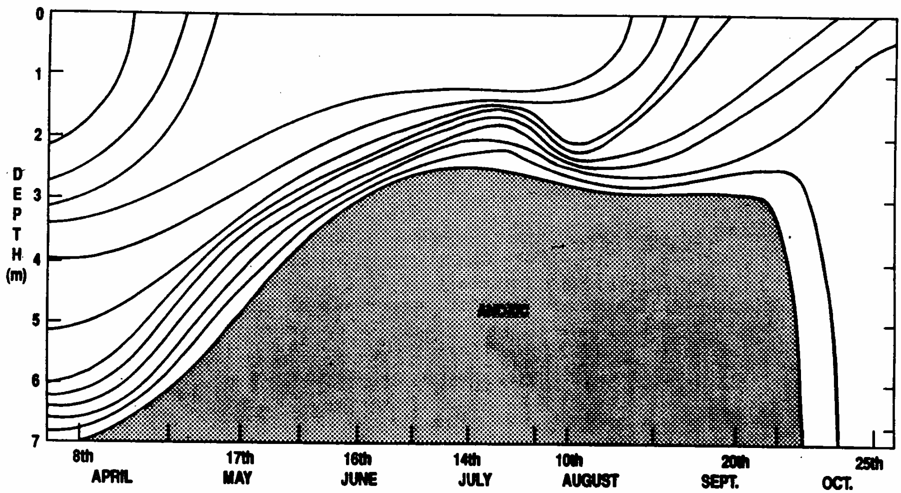


Figure 7. Dissolved oxygen isopleth showing extent of anoxic boundary in Lake Shakamak.

Alkalinity

Alkalinity and other water chemistry data for Lake Shakamak are given in Table 5. Ordinarily, alkalinity values reflect the nature of the rocks within a watershed and their degree of weathering. Alkalinity commonly results from carbon dioxide and water attacking sedimentary carbonate rocks (e.g., limestone) and dissolving some of the carbonate to form bicarbonate solutions (Cole, 1983). Lakes with high alkalinities, and thus high bicarbonate and carbonate ion concentrations, are "well-buffered" because they are able to resist pH changes that occur either naturally as a result of photosynthesis by aquatic plants or by atmospheric acid deposition. The U.S. EPA (1976) recommends a minimum alkalinity of 20 mg/l for maintenance of freshwater aquatic life.

Lake Shakamak is moderately well-buffered in the epilimnion. Alkalinity concentrations increase slightly as photosynthetic assimilation of NO_3^- causes the uptake of H^+ and release of OH^- to maintain charge balance (Stumm and Morgan, 1981). The increase of OH^- ions increases the lake's acid neutralizing capacity, or alkalinity. The hypolimnetic increase in alkalinity can be due to reducing conditions which cause a release of bases (alkalinity).

Conductivity

Conductivity, a measure of the resistance of a solution to electrical flow, remains fairly constant in the epilimnion except for a large increase on August 10. Conductivity is closely proportional to the concentration of the major ions in water (Wetzel, 1983), thus the purer the water is, i.e., the lower its salinity, the lower its conductance of electrical flow will be. The high conductivity value recorded on August 10 resulted from a large increase in dissolved ions but the source of these ions is not known.

pH

The range of pH in a majority of lakes is between 6 and 9 (Wetzel, 1983). Epilimnetic pH values in Lake Shakamak are near neutrality in the spring and rise rather quickly as photosynthetic uptake of CO_2 by phytoplankton and rooted macrophytes increases during the summer months. Since CO_2 is a weak acid its removal causes the pH to increase. The moderate buffering capacity in Lake Shakamak facilitates this pH shift. pH levels in the hypolimnion remains low due to CO_2 generation by bacterial respiration.

Nitrogen

Nitrogen can enter a lake in many forms, primarily from surface runoff, nitrogen fixation by blue-green algae, and atmospheric deposition. Inorganic nitrogen, e.g., ammonia (NH_4^+) and nitrate (NO_3^-), is readily assimilated by growing planks in lakes. Since NH_4^+ is a more energy-efficient source than NO_3^- (Wetzel, 1983), its concentration in epilimnetic waters is often lower. In Lake Shakamak, NN_4^+ and NO_3^- concentrations decrease in the epilimnion as growing plants assimilate it until late summer, when a large increase occurs (Figure 8). This increase is possibly due to a phytoplankton and/or macrophyte die-off which released NH_4^+ and NO_3^- back into the water. External

TABLE 6. Shakamak Water Quality Data

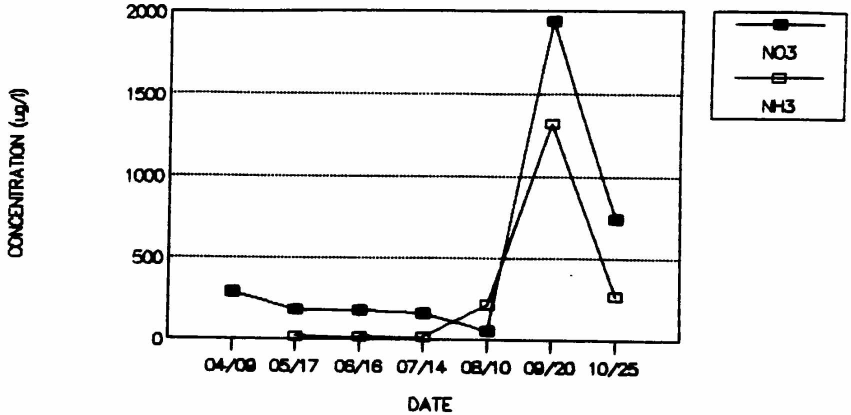
EPILIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)	Secchi Depth (m)
04/09/88	78.0	180.0	7.2	0.29	-	13.9	10.0	0.7
05/17/88	74.0	210.0	7.0	0.18	0.01	29.8	10.0	2.3
06/16/88	88.0	212.0	8.4	0.18	0.01	801.6	234.5	2.0
07/14/88	90.0	210.0	8.2	0.16	0.01	913.5	97.0	1.3
08/10/88	80.0	730.0	9.0	0.06	0.22	58.6	10.0	2.4
09/20/88	94.0	230.0	7.6	1.94	1.32	33.5	11.9	1.0
10/25/88	106.0	140.0	7.5	0.74	0.27	224.8	151.7	4.0

HYPOLIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)
04/09/88	70.0	170.0	6.5	0.29	-	47.5	10.0
05/17/88	84.0	120.0	6.6	0.14	0.09	131.4	30.9
06/16/88	88.0	208.0	6.6	0.11	0.10	1346.3	290.0
07/14/88	110.0	190.0	7.1	0.22	0.01	268.5	254.0
08/10/88	172.0	270.0	6.8	0.04	1.35	1409.9	126.4
09/20/88	216.0	360.0	6.6	1.98	7.84	248.1	190.9
10/25/88	102.0	145.0	7.3	0.54	0.27	188.8	153.4

LAKE SHAKAMAK EPILIMNETIC NO3-NITROGEN AND NH3-NITROGEN



LAKE SHAKAMAK HYPOLIMNETIC NO3-NITROGEN AND NH3-NITROGEN

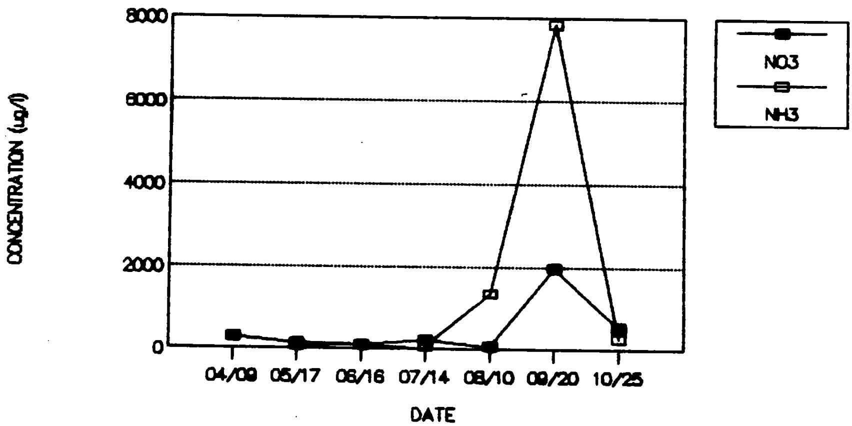


Figure 8. NO_3^- and NH_4^+ concentrations in Lake Shakamak.

sources of inorganic nitrogen were likely a minor contribution due to the lack of precipitation. In the hypolimnion, NH_4^+ is generated by heterotrophic bacteria as a primary end-product of the decomposition of organic matter. "Plankton rain" and previous accumulations of organic matter were likely plentiful to support these bacteria in Lake Shakamak's hypolimnion, as indicated by the very high NH_4^+ concentrations.

The mean epilimnetic inorganic nitrogen for June through August was 0.21 mg/l which is characteristic of mesotrophic lakes. The high epilimnetic inorganic nitrogen concentrations in September (3.26 mg/l) and in October following overturn (1.01 mg/l) are in the range of those reported for highly eutrophic (over productive) lakes in the literature (Wetzel, 1983). As stated previously, these high concentrations are likely due to an algal and/or macrophyte die-off and the subsequent release of inorganic nitrogen by decomposition processes.

Phosphorus

Phosphorus in Table 5 is reported as total phosphorus (TP) and soluble reactive phosphorus (SRP). Since atmospheric sources of phosphorus are relatively minor, the primary source of phosphorus to lakes is from runoff from the watershed which carries both dissolved and particulate forms of phosphorus. Phosphorus is the nutrient which most often controls or limits the growth of plants in lakes. Therefore, it is the nutrient of most concern for lake management.

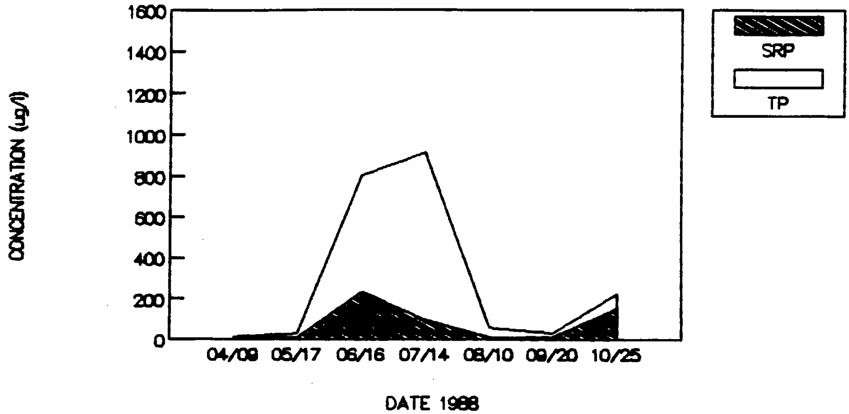
SRP is the form of phosphorus most readily assimilated by plants thus it occurs in relatively low concentrations in the epilimnion of most lakes during the growing season. Epilimnetic SRP in Lake Shakamak remains low except for an increase in June from unknown sources (Figure 9). Hypolimnetic SRP concentrations are elevated due to phosphorus release from the sediments during anoxic (and reducing) conditions.

The high TP concentrations are indicative of the extremely high phytoplankton biomass and represents both organic and inorganic forms of phosphorus. Following fall turnover, the 10/25/88 epilimnetic TP concentration increases greatly due to the mixing of hypolimnetic and epilimnetic waters. Lakes having epilimnetic TP concentrations greater than 100 μg/l are classified as hypereutrophic, the highest trophic classification. This attests to the overproductive and degraded conditions in Lake Shakamak. Lake Shakamak's TP concentration is much higher than that for hypereutrophic Cedar Lake in Lake County which has had a maximum summer epilimnetic [TP] of 350 μg/l (Echelberger et al, 1984).

Transparency

Secchi disk transparency measures the extent to which light is scattered or absorbed by suspended particles. Secchi disk values are rather low for Lake Shakamak (Figure 10). The lowest value, recorded on 4/8/88, was affected by a storm the previous night which left the water extremely turbid. The generally low summertime Secchi disk values are likely due to the turbidity caused by dense phytoplankton populations. The mixing of hypolimnetic waters, virtually

LAKE SHAKAMAK EPILIMNETIC PHOSPHORUS CONCENTRATIONS



LAKE SHAKAMAK HYPOLIMNETIC PHOSPHORUS CONCENTRATIONS

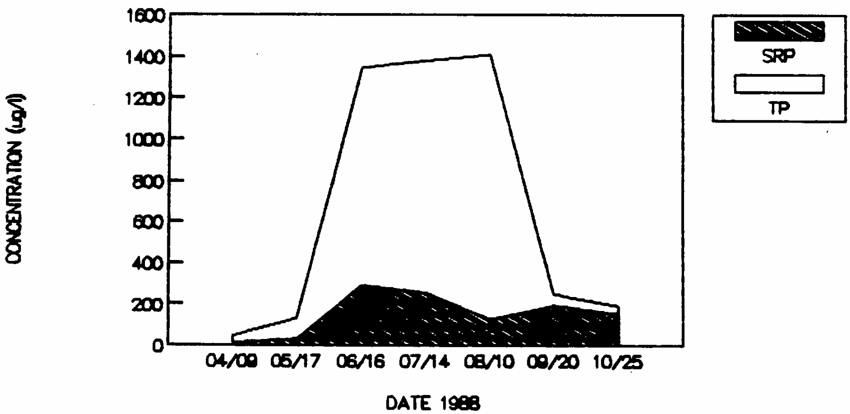


Figure 9. Phosphorus concentrations in Lake Shakamak.

LAKE SHAKAMAK SECCHI DISK TRANSPARENCY

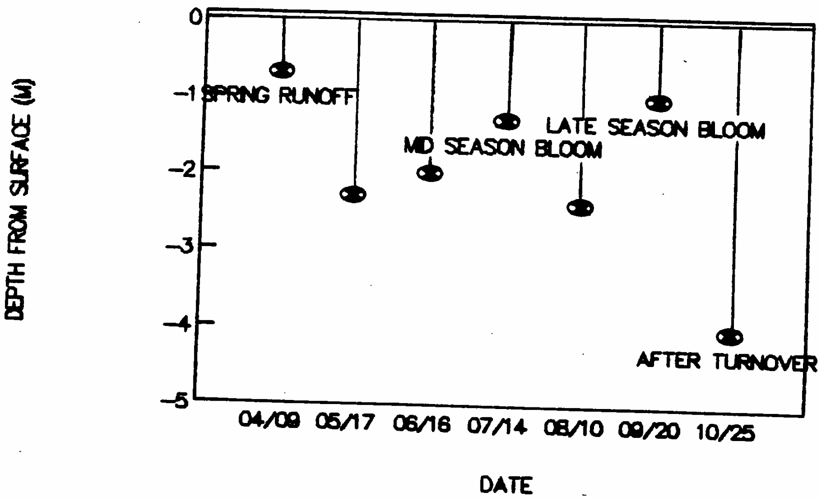


Figure 10. Secchi disk transparency data for Lake Shakamak.

devoid of living phytoplankton, during turnover helps dilute the high epilimnetic turbidity thereby resulting in an increase in measured trans-parency in October. Recorded Secchi disk transparencies for Indiana lakes range from 7 cm in Versailles Lake following a severe storm to 7 meters in oligotrophic Yellowwood Lake (Echelberger et al., 1983; Jones, unpublished data).

Summary

If Lake Shakamak's water quality data (June-August means), including phytoplankton, are used to calculate a trophic state index (TSI) value using the model used to classify Indiana lakes by the Indiana Department of Environmental Management (1986), an index value of 43 is derived. This value places the lake in the intermediate eutrophy category. In the mid-1970s, a TSI of 38 was determined for Lake Shakamak. While there are many lakes in Indiana with higher (more eutrophic) TSI values, Lake Shakamak's water quality is degraded enough to warrent the implementation of an extensive restoration and management plan.

3.2.2 Lake Lenape

Temperature and DO data and profiles for Lake Lenape are given in Figures 11(a) - 11(d). Like Lake Shakamak, Lake Lenape stays well mixed only down to two meters during the summer. By August, the anoxic zone extended from three meters to the bottom. Surface temperatures in August reached 32.0°C, the warmest temperature recorded for the three lakes studied. It is likely that the hot temperatures and drought conditions during the summer of 1988 contributed to the high surface water temperatures recorded. For example, the Lake Lenape surface water temperature in August, 1985 was 26.1°C (Andrews, 1985a). Because maximum photosynthetic production in phytoplankton is temperature dependent, the DO increase at two meters on August 10 may be due to a dense layer of phytoplankton seeking an optimum combination of cooler water with sufficient light for photosynthesis.

Water chemistry data for Lake Lenape are given in Table 6. Many of the same trends observed in the Lake Shakamak data are evident here, however the magnitude of water quality parameter concentrations is lower for Lake Lenape. For example, NO_3^-, NH_4^+, SRP and TP concentrations are lower than those in Lake Shakamak. However, the maximum epilimnetic values recorded for nitrogen and phosphorus would still place Lake Lenape in the eutrophic lake class.

Epilimnetic pH concentrations vary over a greater range during the summer growing season in Lake Lenape possibly due to the slightly lower alkalinities. The increases in hypolimnetic phosphorus suggest that some internal phosphorus release from sediments occurs. Overall, the data suggest that while Lake Lenape is not as eutrophic as Lake Shakamak, conditions are severe enough to warrant immediate management efforts.

LAKE LENAPE
April 8, 1988 SECCHI DEPTH .39 METERS
STATION 1

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	13.0	12.3	119	0
1.0	13.0	12.2	117	0
2.0	12.7	13.0	127	4
3.0	12.0	12.4	120	10
4.0	11.1	11.0	103	12
5.0	10.2	10.0	92	11
6.0	8.0	8.6	76	21
7.0	6.0	8.2	72	11

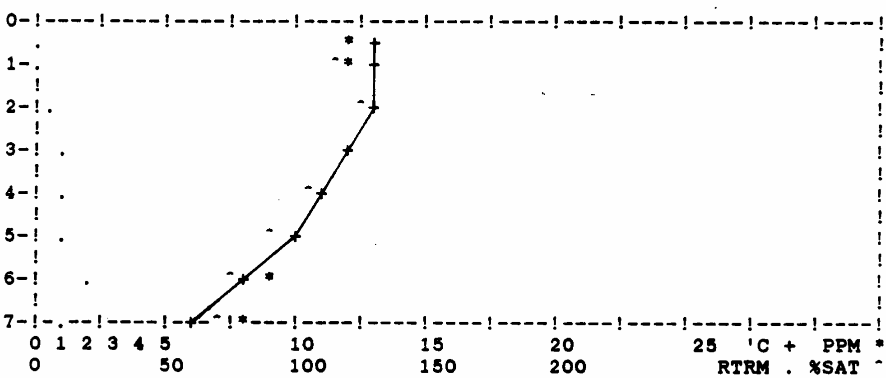


Figure 11(a). Temperature (+) and dissolved oxygen (*) profiles for Lake Lenape on 4-8-88.

LAKE LENAPE
June 16, 1988
STATION 1

SECCHI DEPTH 4.5 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	27.0	8.2	72	0
1.0	27.0	8.0	70	0
2.0	26.0	8.1	71	33
3.0	25.0	7.6	66	32
4.0	19.0	7.2	62	168
5.0	14.0	1.3	10	103
6.0	10.5	0.1	1	50
7.0	8.5	0.1	1	20

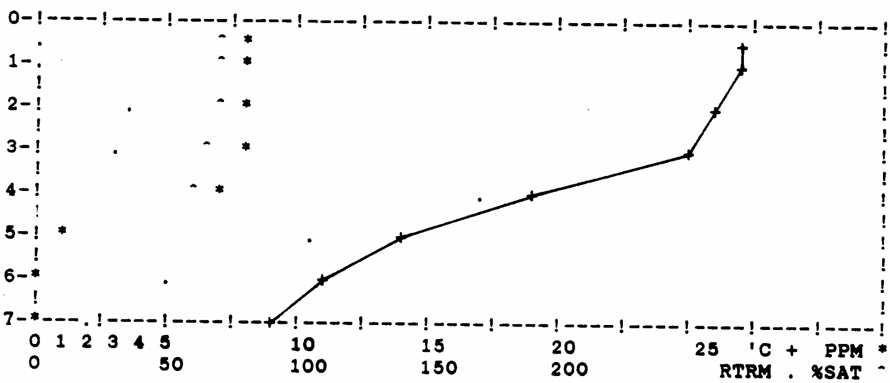


Figure 11(b). Temperature (+) and dissolved oxygen (*) profiles for Lake Lenape on 6-16-88.

LAKE LENAPE
August 10, 1988
STATION 1

SECCHI DEPTH 1.9 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	32.0	10.2	94	0
1.0	32.0	10.4	96	0
2.0	30.0	12.6	122	77
3.0	28.0	1.9	14	72
4.0	24.2	0.1	1	125
5.0	20.0	0.1	1	118
6.0	16.0	0.1	1	91
7.0	11.5	0.1	1	75

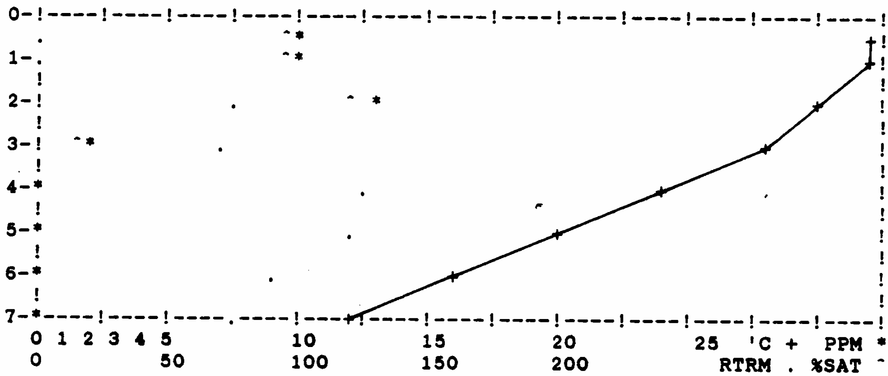


Figure 11(c). Temperature (+) and dissolved oxygen (*) profiles for Lake Lenape on 8-10-88.

LAKE LENAPE
October 25, 1988 SECCHI DEPTH 2.4 METERS
STATION 1

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	12.0	8.2	72	0
1.0	12.0	6.9	59	0
2.0	12.0	6.9	59	0
3.0	12.0	6.4	54	0
4.0	12.0	6.3	53	0
5.0	12.0	6.2	52	0
6.0	12.0	6.2	52	0
7.0	12.0	5.8	48	0

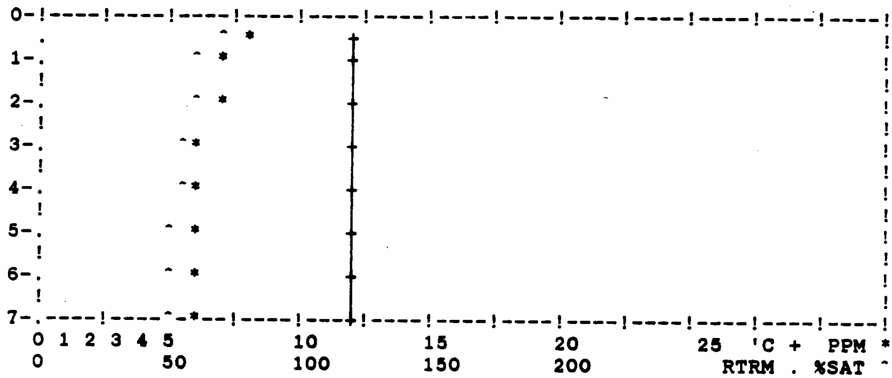


Figure 11(d). Temperature (+) and dissolved oxygen (*) profiles for Lake Lenape on 10-25-88.

TABLE 7. Lake Lenape Water Chemistry Data

EPILIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)	Secchi Depth (m)
04/09/88	66.0	150.0	6.5	0.28	-	37.9	10.0	0.4
06/16/88	78.0	232.0	7.6	0.10	0.01	24.4	10.0	4.6
08/10/88	71.0	200.0	9.9	0.04	0.04	165.0	10.0	1.9
10/25/88	96.0	140.0	7.4	0.49	0.15	104.5	28.8	2.4

HYPOLIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)
04/09/88	66.0	140.0	6.5	275.0	-	25.2	10.0
06/16/88	84.0	195.0	6.7	75.0	28.0	19.9	15.8
08/10/88	102.0	185.0	7.2	32.0	29.0	480.6	62.4
10/25/88	92.0	140.0	7.4	351.6	150.1	93.6	33.9

3.2.3 Lake Kickapoo

Temperature and dissolved oxygen data and profiles for Lake Kickapoo are given in Figures 12(a) - 12(d). The depth of Lake Kickapoo's epilimnion is 3-4 meters in August, the deepest of the three lakes. Lake Kickapoo stays well-oxygenated down to at least six meters throughout the summer. Epilimnetic DO concentrations are lower in August than those for lakes Shakamak and Lenape due to the lower phytoplankton production in Lake Kickapoo.

Water chemistry data presented in Table 7 shows that Lake Kickapoo has the best water quality of the three lakes. Epilimnetic nitrogen and phosphorus concentrations are not excessive and Secchi disk transparency is excellent.

LAKE KICKAPOO
April 8, 1988
STATION 1

SECCHI DEPTH 1.3 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
1.0	12.0	11.0	103	0
2.0	12.0	11.9	114	0
3.0	12.0	12.4	120	0
4.0	11.9	12.7	124	1
5.0	11.0	12.1	116	12
6.0	11.0	12.0	115	0
7.0	11.0	11.5	109	0
8.0	11.0	11.5	109	0
9.0	11.0	11.5	109	0
10.0	10.5	11.0	103	6
11.0	10.6	9.0	80	-1
12.0	10.3	9.0	80	4
13.0	9.9	8.5	75	5

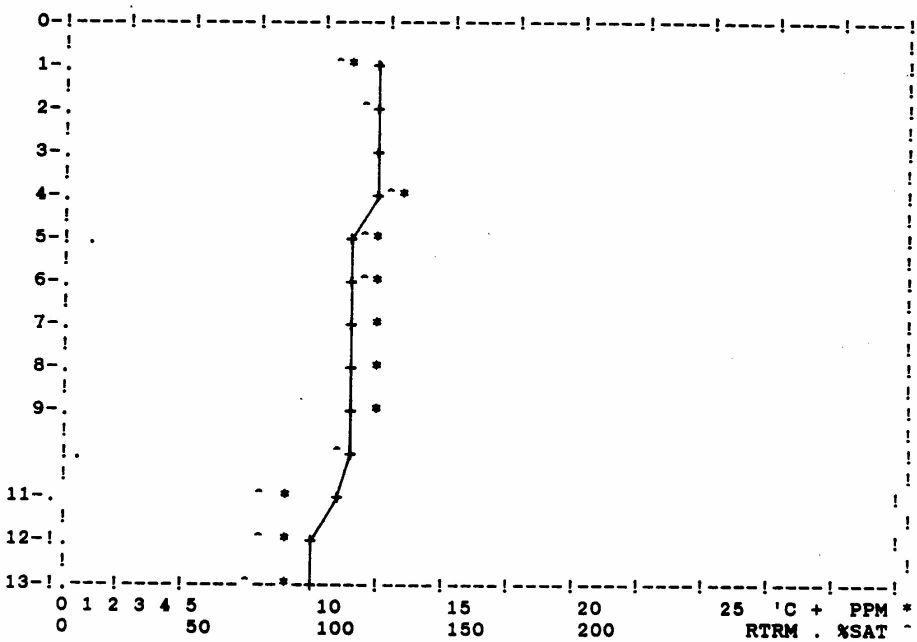


Figure 12(a). Temperature (+) and dissolved oxygen (*) profiles for Lake Kickapoo on 4-8-88.

LAKE KICKAPOO
June 16, 1988 SECCHI DEPTH 5.9 METERS
STATION 1

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	27.0	8.4	74	0
1.0	27.0	8.4	74	0
2.0	27.0	8.5	75	0
3.0	26.0	8.5	75	33
4.0	25.0	8.5	75	32
5.0	22.0	6.5	55	89
6.0	18.0	3.8	30	102
7.0	16.0	1.5	11	43
8.0	14.0	0.1	1	37
9.0	12.0	0.1	1	31
10.0	11.0	0.1	1	13
11.0	10.5	0.1	1	6
12.0	10.0	0.1	1	6

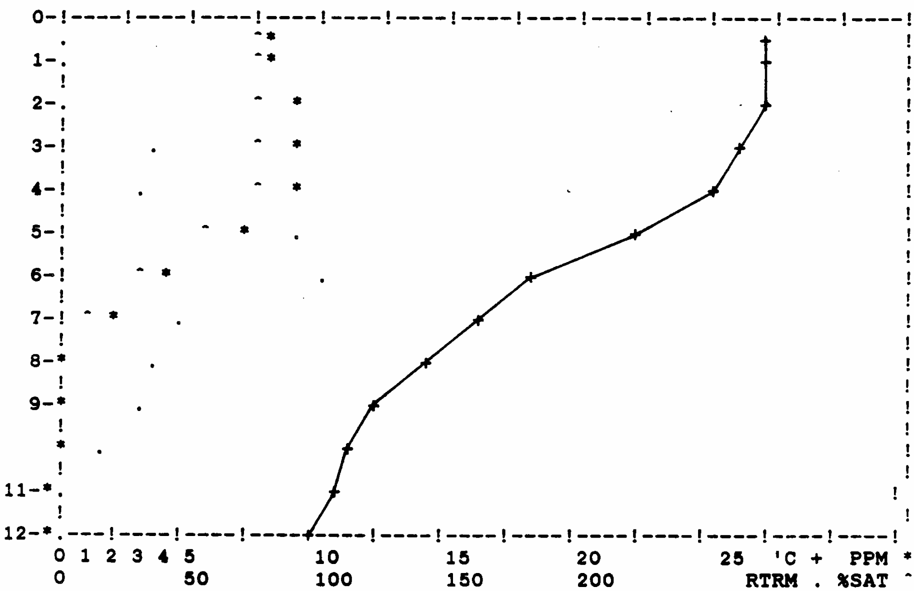


Figure 12(b). Temperature (+) and dissolved oxygen (*) profiles for Lake Kickapoo on 6-16-88.

LAKE Kickapoo
August 10, 1988 SECCHI DEPTH 1.8 METERS
STATION 1

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	31.0	8.6	76	0
1.0	30.5	8.7	77	19
2.0	30.5	8.7	77	0
3.0	30.5	8.5	75	0
4.0	30.0	8.3	73	19
5.0	28.0	6.3	53	72
6.0	24.0	4.5	36	131
7.0	20.0	0.2	1	112
8.0	16.0	0.2	1	91
9.0	14.0	0.2	1	37
10.0	11.5	0.2	1	38

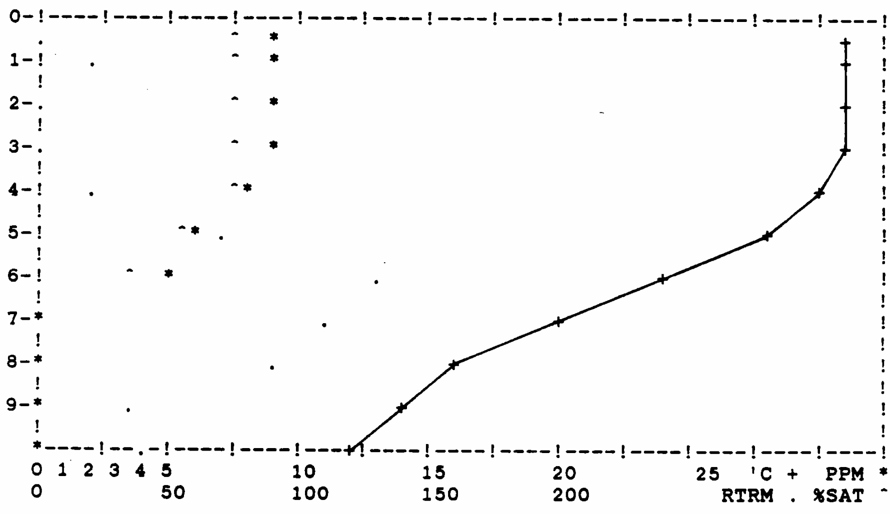


Figure 12(c). Temperature (+) and dissolved oxygen (*) profiles for Lake Kickapoo on 8-10.88

LAKE Kickapoo
October 25, 1988
STATION 1

SECCHI DEPTH .91 METERS

DEPTH M	TEMP 'C	DO mg/L	%SAT	RTRM
0.5	13.5	7.2	62	0
1.0	13.5	6.8	58	0
2.0	13.5	6.4	54	0
3.0	13.5	6.2	52	0
4.0	13.5	6.2	52	0
5.0	13.5	6.3	53	0
6.0	13.5	6.5	55	0
7.0	13.5	6.4	54	0
8.0	13.5	6.4	54	0
9.0	13.5	6.4	54	0
10.0	13.5	6.4	54	0

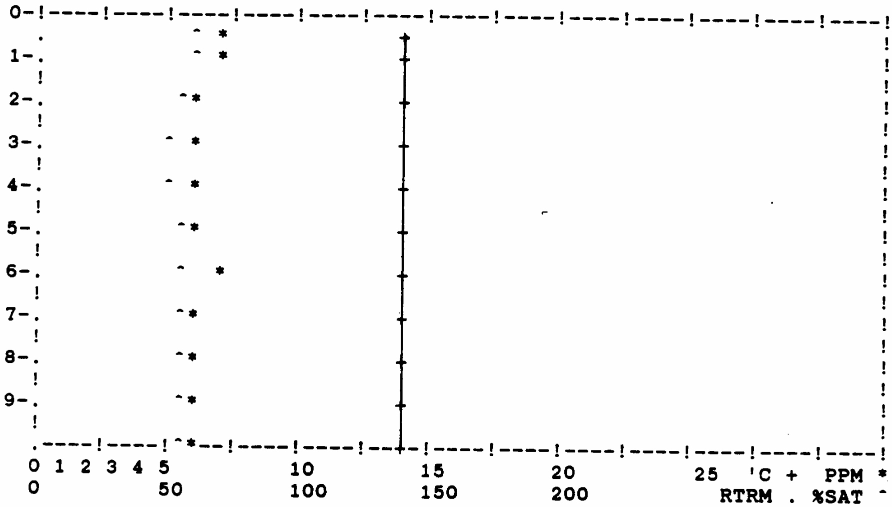


Figure 12(d). Temperature (+) and dissolved oxygen (*) profiles for Lake Kickapoo on 10-25-88.

TABLE 8. Lake Kickapoo Water Chemistry Data

EPILIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)	Secchi Depth (m)
04/09/88	68.0	125.0	7.1	-	-	49.9	10.0	1.4
06/16/88	78.0	198.0	7.5	0.07	0.01	65.3	10.0	5.9
08/10/88	70.0	190.0	8.9	0.02	-	80.0	20.0	6.2
10/25/88	88.0	130.0	7.4	0.26	0.10	48.2	10.0	3.0

HYPOLIMNION

Date	Alkalinity (mg CaCO3/l)	Conductivity (umhos)	pH	NO_3^- Nitrogen (mg/l)	NH_4^+ Nitrogen (mg/l)	Total Phosphorus (ug/l)	Soluble Reactive Phosphorus (ug/l)
04/09/88	74.0	140.0	6.9	-	-	23.4	10.0
06/16/88	104.0	140.0	6.4	0.07	0.60	401.7	249.4
08/10/88	81.0	155.0	7.8	0.02	-	65.5	221.4
10/25/88	80.0	135.0	7.6	0.24	0.10	15.9	14.1

4.0 SEDIMENTS

4.1 METHODS

Because the nature of this study placed special emphasis on sedimentation problems in Lake Shakamak, a number of sediment-related characteristics were investigated. Sediment depths in Lake Shakamak were determined along five range lines and several individual locations (Figure 13) according to methods used by the Corps of Engineers (1961) and Soil Conservation Service (1968). Intact sediment cores were extracted from each location indicated (57 total) with a 1.5 inch diameter piston core sampler that was pushed into the sediments. Each core was begun above the sediment-water interface to keep that important boundary undisturbed. The resulting cores included 10-15 cm of water at the top and 85-90 cm of sediment below.

Each core sample was extruded in the boat and examined immediately to determine the depth of sediments that had accumulated since the lake was impounded. The alluvial/colluvial soil - lacustrine sediment boundary in an intact core is usually very distinct and is indicated by changes in texture, color and particles. For example, modern lacustrine sediments are finer and darker in color (due to organic matter content) than old alluvial/colluvial soils. The distance from this boundary to the top of the extruded core represents the depth of accumulated sediments.

Cores taken along the north-south axis of the lake and from Range Lines 4 and 2 were wrapped and returned intact to our laboratory for further study. Particle size distribution was determined for the surficial sediments by the hydrometer method (Black, 1965). Percent organic matter was determined by comparing the differences between dry weights and ash weights.

In addition to the analysis of sediment cores, the status of sediment traps and culverts in Lake Shakamak's inlet streams was visually inspected and a model was used to estimate watershed sources of sediment.

4.2 SEDIMENT DEPTH

Table 8 gives sediment and water depth data and Figures 14(a) - 14(f) show vertical cross sections along each range line. The greatest sediment accumulation is along Range Line (RL) - 2, where 14.2 percent of the original cross-sectional area has filled in with sediments. The thickest sediment deposits are in the deepest part of the original cross-section, presumably the original stream channel. The sub-watershed that drains into this lake lobe is not the largest of the sub-watersheds but it does include portions of the city of Coalmont (Table 9). However, this sub-watershed area was not predicted to have higher erosion by the Universal Soil Loss Equation (see Section 4.5).

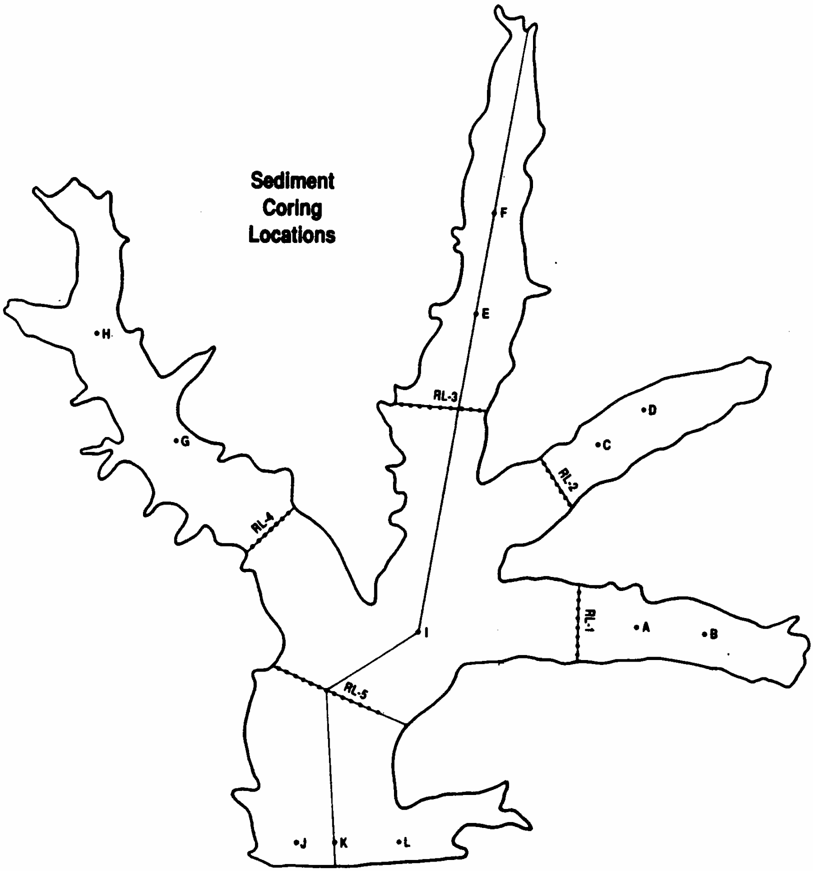


Figure 13. Locations of sediment coring range lines and sampling points.

TABLE 8. Water Depth and Sediment Thickness at Sample Locations in Lake Shakamak (in meters)

	Water Depth[1]			Sediment Thickness[2]		
Sample Location	Mean	Maximum	Minimum	Mean	Maximum	Minimum
RL - 1	3.00	3.90	1.80	0.288	0.50	0.15
RL - 2	2.47	3.25	0.75	0.397	0.78	0.05
RL - 3	2.91	3.70	1.20	0.267	0.42	0.10
RL - 4	4.11	4.85	1.70	0.203	0.29	0.12
RL - 5	5.44	6.00	3.00	0.358	0.43	0.24
A	2.75			0.33		
B	1.80		A	0.40		A
C	2.40		P	0.35		P
D	1.50		P	0.70		P
E	2.75	N	L	0.23	N	L
F	1.60	O	I	0.30	O	I
G	3.90	T	C	0.20	T	C
H	2.00		A	0.33		A
I	5.20		B	0.38		B
J	6.90		L	0.30		L
K	6.10		E	0.40		E
L	5.20			0.37		

[1]Water depths presented for individual sites (A-L) are actual values (not means).

[2]Sediment thickness presented for individual sites (A-L) are actual values (not means).

The smallest percentage of sediment accumulation is in Lobe #4 where 4.98 percent of the original cross-sectional area is filled in. The drainage area for this lobe is the largest of the sub-watersheds so one might expect higher sedimentation rates here, however slopes in this sub-watershed are somewhat more gentle. Lobes #1 and #3 both have between 8-9 percent sedimentation while RL - 5, across the main body of the lake and farthest from the stream mouths has filled in approximately 6.5 percent.

While it is difficult to estimate precisely the gross whole-lake sedimentation percentage for Lake Shakamak from just five range lines, the arithmetic mean sedimentation for these range lines is 8.56 percent. When this value is divided by the lifetime of Lake Shakamak (59 years) a relatively low gross

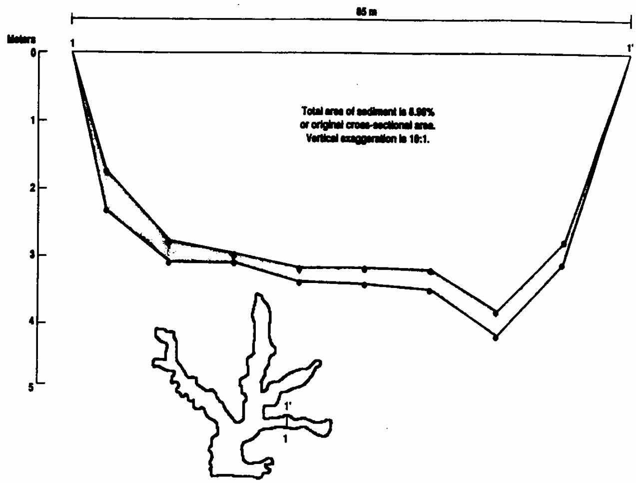


Figure 14(a). Cross section showing lake bottom configuration and sediment thickness for Range Line 1.

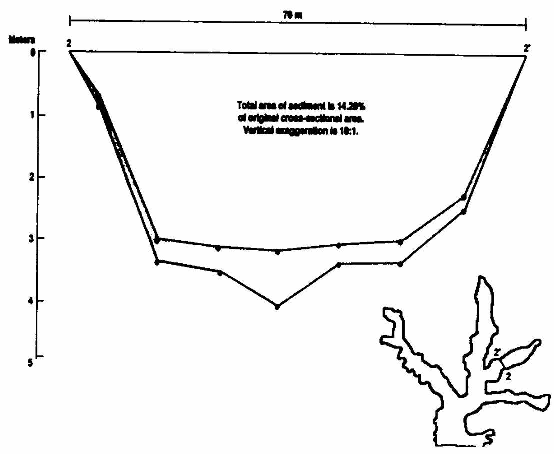


Figure 14(b). Cross section showing lake bottom configuration and sediment thickness for Range Line 2.

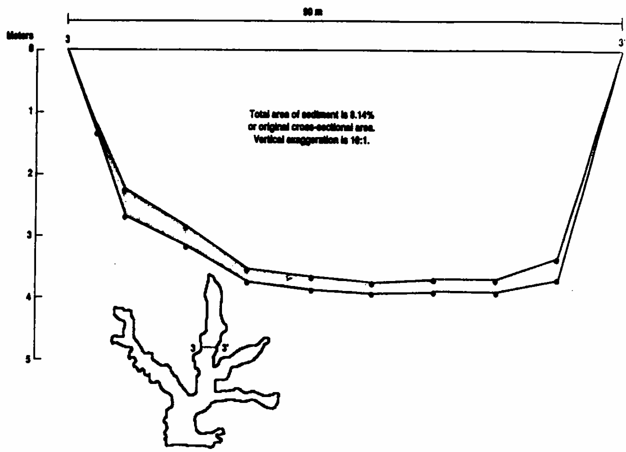


Figure 14(c). Cross section showing lake bottom configuration and sediment thickness for Range Line 3.

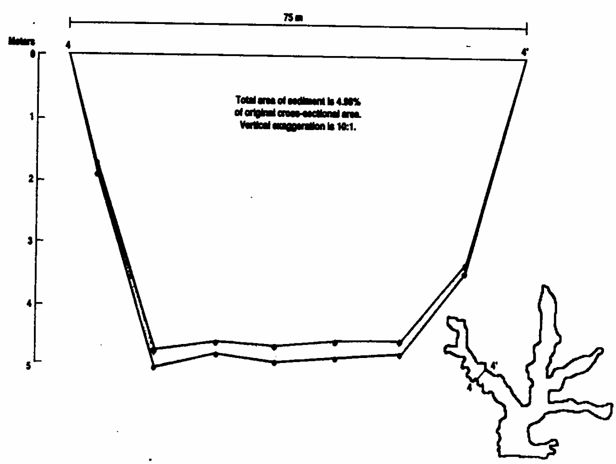


Figure 14(d). Cross section showing lake bottom configuration and sediment thickness for Range Line 4.

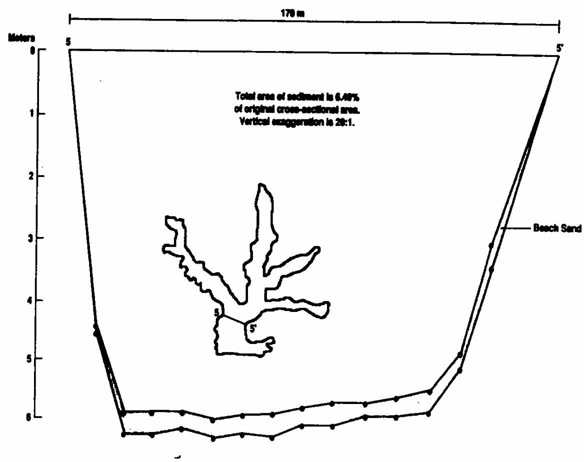


Figure 14(e). Cross section showing lake bottom configuration and sediment thickness for Range Line 5.

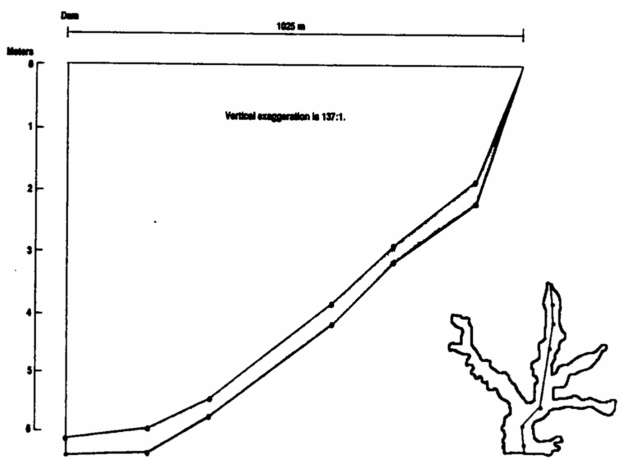


Figure 14(f). Cross section showing lake bottom configuration and sediment thickness for the north-south axis of the lake.

TABLE 9. Lake Shakamak Sub-Watershed Areas

Sub-Watershed[1]	Area Acres(ha)
RL - 1	204 (82)
RL - 2	188 (76)
RL - 3	178 (72)
RL - 4	205 (83)

[1]Designated according to which lobe of the lake and sediment range line it drains into.

whole-lake sedimentation rate of 0.15 percent per year is calculated. This is similar to the 0.17 percent per year sedimentation rate for Lake Lemon (Hartke and Hill, 1974). In a study of estimated sediment capacities for 27 Corps of Engineers reservoirs, most had sedimentation rates exceeding that of Lake Shakamak and several had rates exceeding 0.9 percent per year (Corps of Engineers, 1961). In a 1965 survey of Indiana reservoirs, the following sedimentation rates were reported: Shaefer Lake - 0.28%/yr.; Whitewater Lake - 0.55%/yr.; Brush Creek Reservoir - 0.93%/yr; and Cagles Mill - 0.07%/yr. (Department of Natural Resources, 1965)

4.3 SEDIMENT CHARACTERISTICS

4.3.1 Texture

Of the various sediment parameters, texture, or particle size of the materials, is one of the more important determinations because it can be related to the watershed source of the sediments as well as to their distribution throughout the lake. As stream water carrying suspended sediments flows into a lake, the energy available to keep the sediments suspended decreases with distance from the mouth of the stream. Rooted macrophytes are an important factor in reducing the energy of flowing water. Because of this, heavier sand particles, which require more energy to stay in suspension, drop out first, followed by silt and finally clay particles. Thus, in many reservoirs, there is a continuum of different-sized sediment particles (sand-silt-clay) deposited between the stream mouth and the dam.

Table 10 and Figure 15 show the results of textural analyses of various Lake Shakamak sediment cores. Of particular interest is the particle size comparisons from RL-2 and RL-4. Clay-sized particles dominate in the RL-2

TABLE 10. Textural Analysis of Lake Shakamak Sediment

Core ID	% Sand	% Silt	% Clay
RL2, #4	33.4	22.2	44.4
RL4, #6	58.4	8.3	33.3
RL3, #4	39.8	32.4	37.9
I	28.7	57.0	14.3
RL5, #9	22.2	62.2	15.6
K	50.4	27.1	22.5

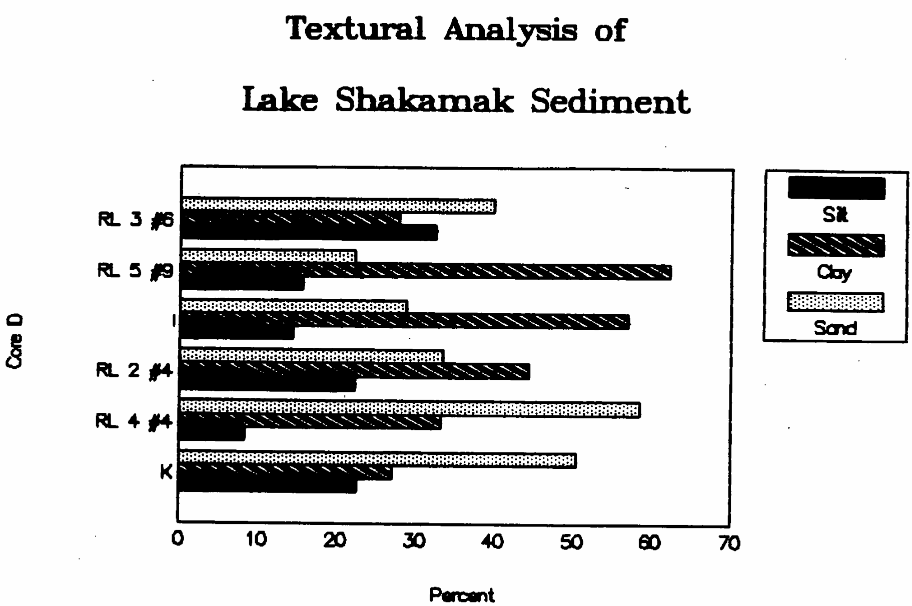


Figure 15. Texture analysis of Lake Shakamak sediment

core which is also the lake lobe where sediment accumulation was thickest. This suggests that water flowing into and through Lobe 2 has insufficient velocity to flush the smaller sediment particles from the lobe into the main lake body. Therefore, the sediments accumulate at a higher rate in this lobe. The small sub-watershed size and the presence of several flood control reservoirs could contribute to lower water discharge into this lobe.

Lobe 4 on the other hand drains a larger sub-watershed, which in turn could produce greater discharge and better sediment flushing energy. Sediments from the Lobe 4 core are dominated by sand particles.

Sediment cores from the main lake body (RL-5 and I) are dominated by smaller clay-sized particles as expected, but those from Core K, closest to the dam, are dominated by sand. It is unlikely that sand suspended in the inlet streams could be carried this far. A more likely explanation for the source of this sand is that it was eroded from the nearby beach or from the dam itself.

4.3.2 Organic Matter

Organic matter in soils is composed of plant material in various stages of decomposition. The organic matter content in terrestrial soils varies widely from just a trace to 15 percent. The average for 30 Nebraska soils was 3.8 percent while a well-drained Indiana forest soil had an organic matter content of 8 percent (Buckman and Brady, 1969).

The organic matter content in surficial lake sediments can also vary widely depending on the internal production of phytoplankton and macrophytes and the introduction of external organic matter from watershed erosion. Some representative values for Indiana lakes are 4.3 percent for Lake Lemon (Zogorski et. al., 1986) and 17.5 percent for Cedar Lake (Echelberger et. al., 1983).

The organic matter content for Lake Shakamak sediments is presented in Table 11 and Figure 16. Values for surficial sediments range from 7.8 percent in Lobe 4 to 13.8 percent at Site K. Because recent organic matter deposits are rather flocculent, it is common for wave action and gravity to transport them downslope to the deepest part of the lake. This 'focusing' process likely contributed to the higher organic matter content at Site K. The high organic matter percentages in Lake Shakamak sediments confirm that organic sedimentation from internal plant production is an important process in the lake. Organic matter content in sediments decreases with depth due to the gradual oxidation of older organic matter deposits.

4.4 STREAM SEDIMENTATION

The park road which encircles Lake Shakamak forms an artificial barrier to sediments and water entering the lake. Any drainage outside the road must flow through the culverts to the lake. A number of check dams were

TABLE 11. Organic Matter Content of Lake Shakamak Sediments

Core ID	Sediment Surface	Mid-Core	Bottom Core
RL2, #5 **	7.84	7.28	5.26
RL4, #6 *	11.26	8.11	3.85
RL3, #4 *	10.73	9.23	8.21
I	12.38	11.97	9.06
RL5, #9	11.72	11.53	9.19
K	13.77	14.21	10.74

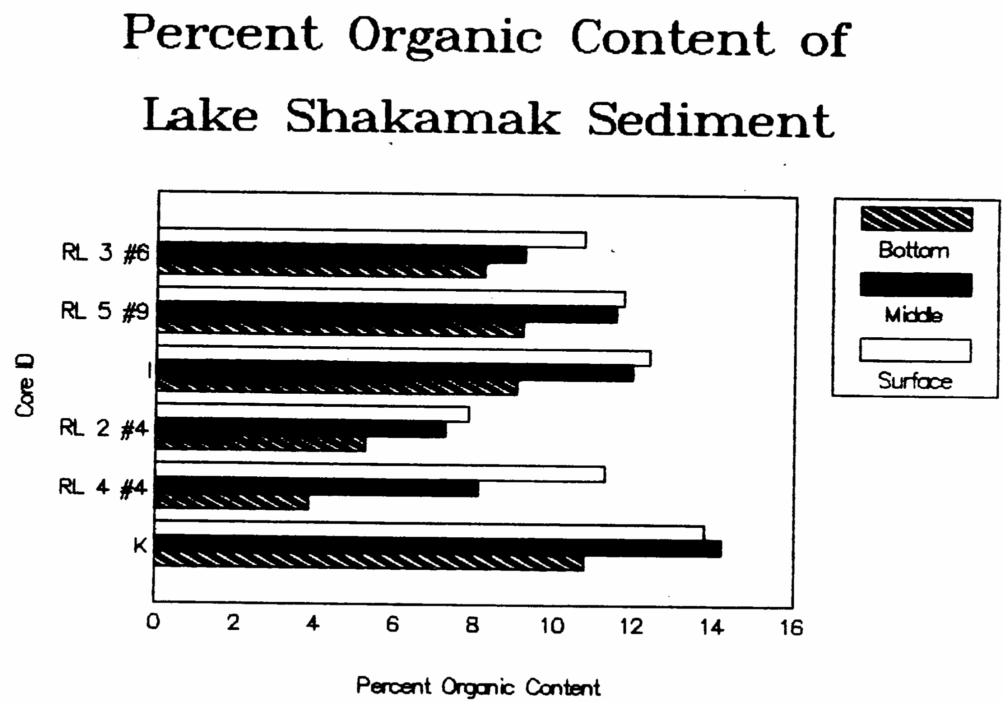


Figure 16. Organic matter content of Lake Shakamak sediments

constructed across these streams on the watershed side of the road in the 1930s (Figure 17) in an effort to trap sediments before they entered the lake (Department of Natural Resources, 1986). Visual inspection shows that today these check dams and several culverts, are filled in and dilapidated.

Figures 18(a) - 18(d) show plan view sketches of the check dams and immediate surroundings at sites 1, 2, 3 and 5. The following problems were noted during the inspection:

1. The check dams are in a state of disrepair.

2. Sediments have filled in behind the check dams and in some cases, have topped the dams.

3. Culverts below the check dams contain sediment deposits.

4. Some culverts have been undercut with water.

5. Sediments transported to the lake side of the culverts have modified the natural drainage pattern causing the water to either back up or flow overland.

The fact that the check dams are filled with sediments is proof that they have worked in keeping sediments out of Lake Shakamak. The lack of maintenance has obviously compromised their ability to function properly. Check dams, or dry sedimentation basins as they are called now, require periodic cleaning out to maintain their effectiveness. Suggested improvements for managing the sedimentation basins are discussed in Section 7.2.2.

4.5 POTENTIAL SOIL LOSS

The Universal Soil Loss Equation (USLE) was used to estimate potential soil loss in the watershed. (Note: Since the USLE is set up for English units, English units were used in the calculations.) The USLE uses six factors which influence soil loss to determine potential loss from a particular land unit (Wischmeir and Smith, 1978).

$$A = RKLSCP$$

A = Potential soil loss (tons/acre/year)
R = Rainfall erosion index (1/year)
K = Soil erodibility factor
L = Slope length factor (feet)
S = Slope steepness factor (percent)
C = Cover and management factor
P = Support practice factor (tillage factor)

A Geographic Information System (GIS) was used to calculate A for 400 m^2 cells throughout the Lake Shakamak watershed. A value of 205 was used for R over the entire watershed. Values for K,L,S,C, and P were calculated using

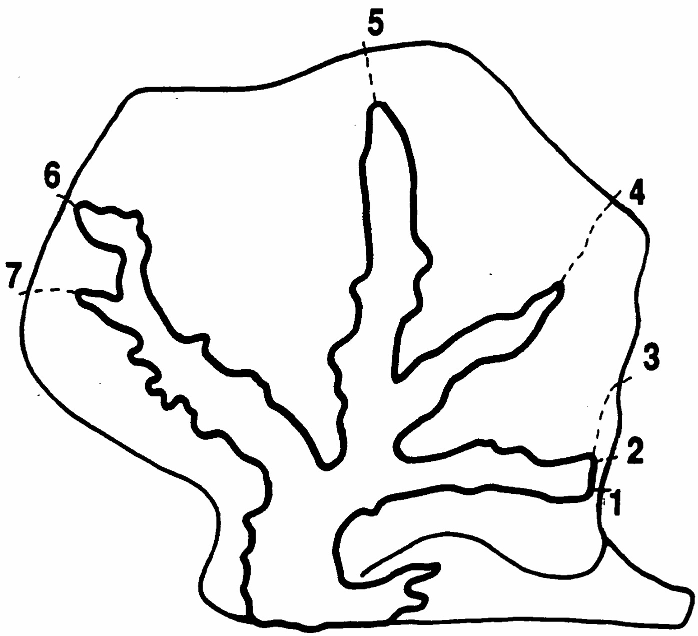


Figure 17. Check dam and culvert sedimentation sites.

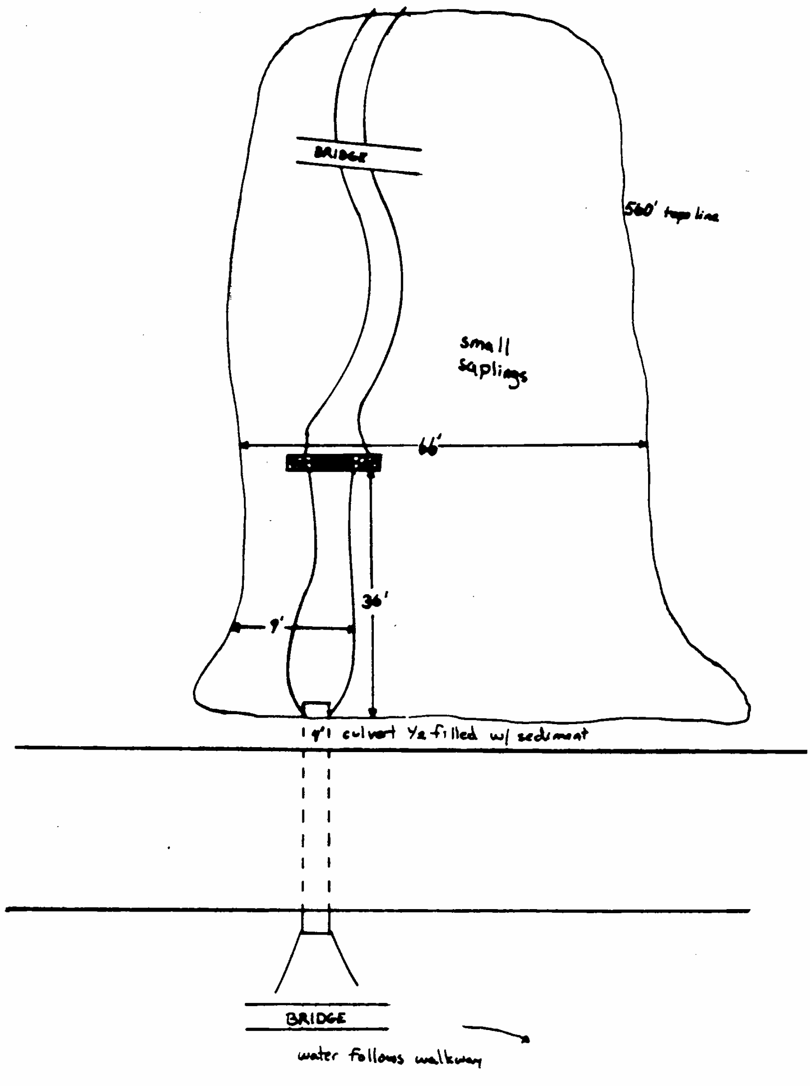


Figure 18(a). Plan view of check dam and surroundings at Site 1.

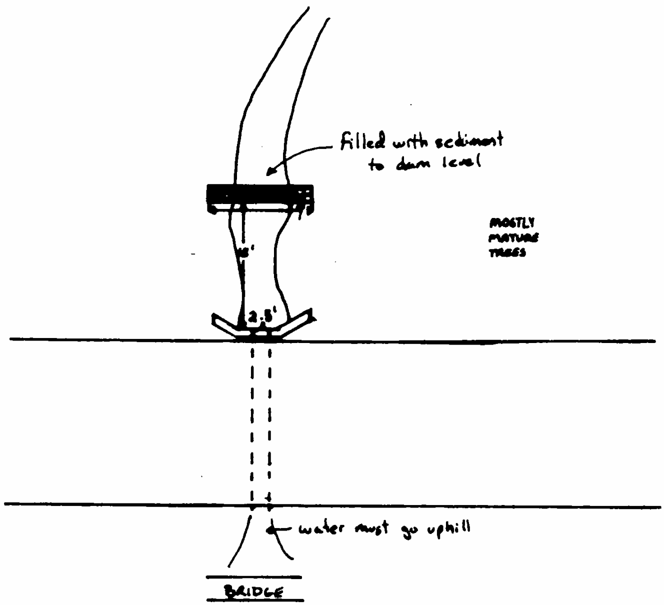


Figure 18(b). Plan view of check dam and surroundings at Site 2.

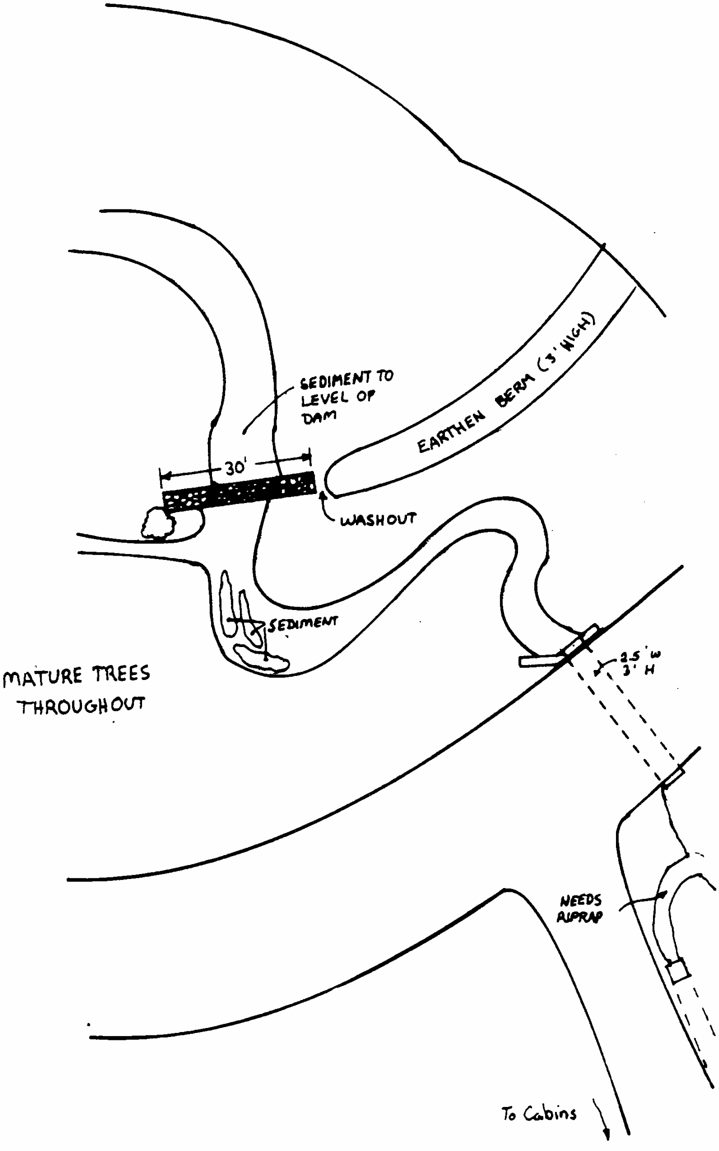


Figure 18(c). Plan view of check dam and surroundings at Site 3.

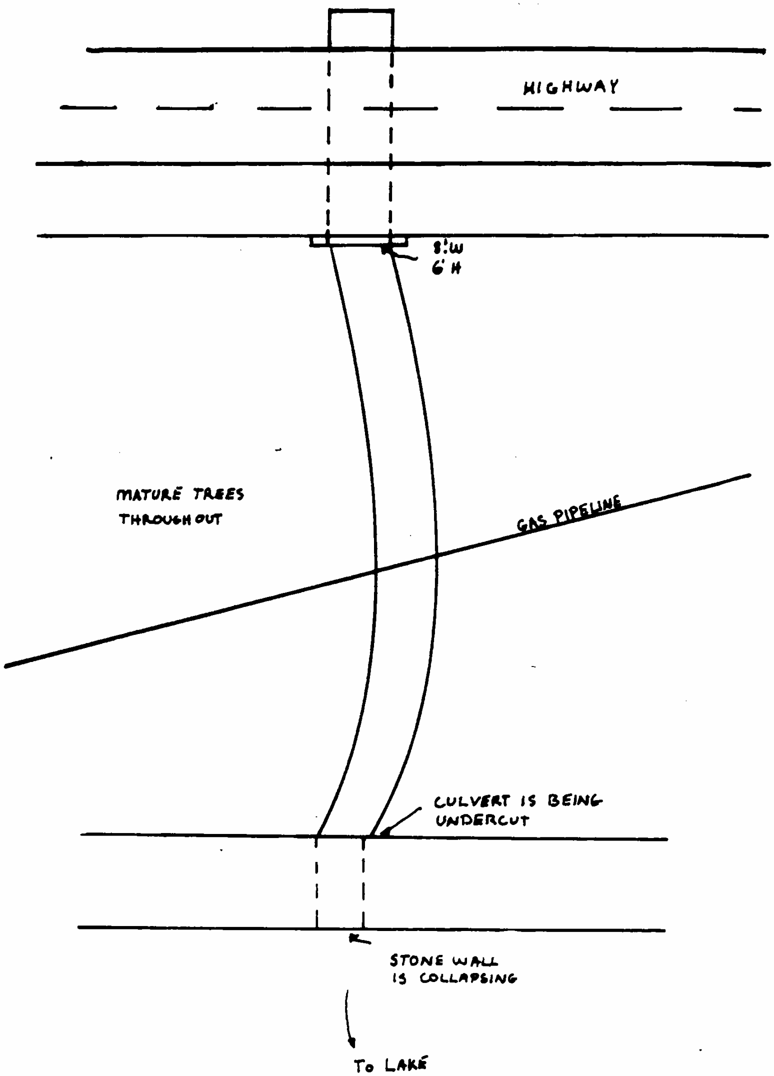


Figure 18(d). Plan view of Site 5.

the GIS database. All soils in the watershed had K values of 0.43 or 0.37 (Clay, Greene, and Sullivan County Soil Surveys). A slope length of 600 feet was applied to the entire watershed and three slope classes were used (0.5, 3, and 8%). This resulted in a combined LS value of 0.137, 0.492, or 2.43 for each cell in the watershed. Cover management factor values, C, were applied to each land use: agriculture-0.5, forested-0.004, and urban/residential-0.001. Finally, support practice factor values were assigned by land use and slope. Contour tillage was assumed throughout the agricultural area. Values of 0.8, 0.6, or 0.5 were assigned to cells within the watershed. Each of these factors comprises a layer in the GIS database. The values of the same cell on each layer were multiplied to generate a final map depicting A, potential soil erosion throughout the watershed. The total area of each category of soil loss (tons/acre/year) was calculated. An average potential soil loss for the watershed of 2.54 tons/acre/year (6.27 tons/ha/year) was obtained (Table 12). This amounts to an estimated annual soil loss for the watershed of 2,540 tons/year. Remember that all of this eroded soil does not reach Lake Shakamak. Much of it is displaced to lower land areas or is deposited in the flood plain of the streams. Figure 19 identifies areas where high potential soil loss exists. One such area is at the tip of the central tributary of the lake. Conservation tillage is currently not practiced in the agricultural fields in this area. Other potential source areas reflect how important slope is in soil loss.

The presence of erodible soils in the watershed suggests the need for action to prevent erosion and to mitigate the effects of erosion. Conservation tillage, use of erosion controls during construction, and construction of sedimentation basins are all effective soil management techniques. Conservation tillage could prevent much of the soil loss from the Vigo silt loam soils. Erosion controls during construction activities can reduce short-term heavy soil losses. Sedimentation basins provide a long-term protection to the lake from any source above the sedimentation basin.

TABLE 12. Estimation of Soil Loss in the Lake Shakamak Watershed

Soil Loss Category (tons/acre/yr)	Total Area In Category (acres)	Total Tons (Yr)
1	48.93	48.93
2	80.55	161.10
3	124.94	374.82
7	0.09	0.63
9	0.19	1.71
11	25.60	281.60
13	128.59	1,671.67

Total Tons for Watershed	2,540.46
Total Acres in Watershed	1,000
Average Sediment Yield	2.54 tons/acre/yr

Figure 19. Soil management areas in Lake Shakamak's watershed. Lightest areas are those with the greatest potential for soil erosion, given current land uses.

5.0 BIOLOGICAL RESOURCES

5.1 AQUATIC MACROPHYTES

Fringe wetlands, wetlands found along a lake margin, perform a number of important functions. Aquatic macrophytes in a fringe wetland produce oxygen, stabilize shoreline soils, dampen the erosive effects of waves, trap suspended sediments, and provide food, shelter, nesting and spawning habitat for fish, wildlife and macroinvertebrates (Table 13). Macrophytes may also draw nutrients from the sediments and release them into the water, hamper boat access and swimming, and may be too dense for positive wildlife benefits. Lake managers often employ many techniques to remove aquatic macrophytes without due consideration to their positive attributes.

An aquatic macrophyte survey was performed on July 31, 1988 at Lake Shakamak. The entire lake was surveyed from shore and by canoe. Measurements and identifications were performed on site. Nine dominant species were identified and mapped (Figure 20). Approximately one half of the lake surface area (47 percent) overlies, rooted aquatic macrophytes. The dominant species are coontail (*Ceratophyllum demersum*) and eurasian water milfoil (*Myriophyllum spicatum*). Both of these are submerged species. The lakeward extent of these species is along the 10 foot contour. Other species include spatterdock (*Nuphar variegatum*), water-lily (*Nymphaea odorata*), pickerelweed (*Potenderia cordata*), wild celery (*Vallisneria americana*), Cat-tail (*Typha sp.*), and naiad (*Najas flexilis*). Some attributes of these species are listed in Table 13.

An evaluation of aerial photographs (from the Indiana Department of Transportation) reveal that from 1958 to 1978, the aerial extent of the macrophytes has not changed significantly. Thus, appears that the area of macrophyte coverage in Lake Shakamak is rather stable.

Water milfoil and coontail both obtain nutrients from the sediments. While net phosphorus release by growing *M. spicatum* can be small, about 0.37 $mg/m^2/$ day (Carignan and Kalff, 1981), it does represent a net seasonal input to the littoral zone since the phosphorus is derived from the sediments. Of greater significance is phosphorus release from macrophytes when they die back. Water milfoil may have several die-off periods during the year starting in late July and continuing into fall. During these die-off periods, phosphorus is released into the water (Landers and Lottes, 1983). This release can be large enough to increase phytoplankton production and may cause species composition to shift from green to blue-green species. This phenomenon may have contributed to the increased phosphorus concentration in the lake which started in July.

The submerged macrophytes may also provide needed oxygen to the lower part of the epilimnion. Anoxia reaches above three meters during July and August. Oxygen production by coontail and water milfoil may help prevent the anoxic boundary from extending closer to the surface. On the other hand, decaying macrophyte biomass increases the oxygen demand near the sediments.

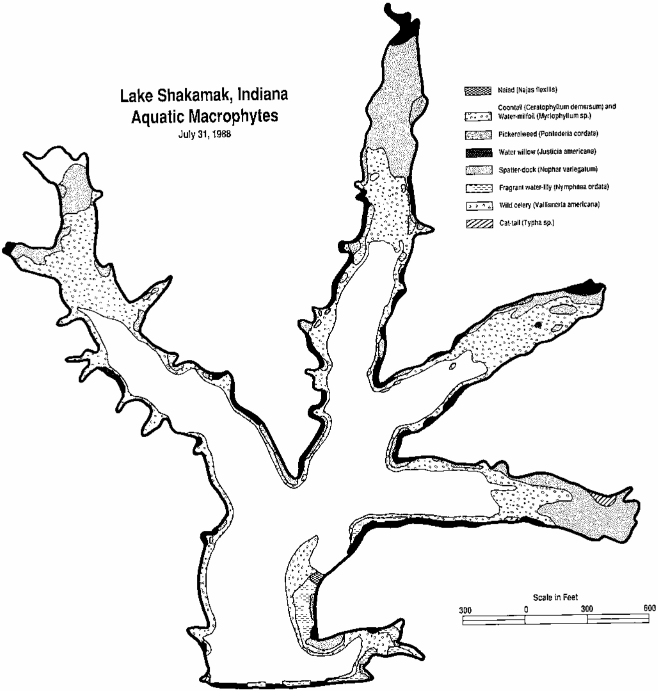

Lake Shakamak, Indiana
Aquatic Macrophytes
July 31, 1988
Naiad (Najas flexilis)
Coontail (Ceratophyllum demersum) and Water-milfoil (Myriophyllum sp.)
Pickerelweed (Pontederia cordata)
Water willow (Justicia americana)
Spatter-dock (Nuphar variegatum)
Fragrant water-lily (Nymphaea ordata)
Wild celery (Vallisneria americana)
Cat-tail (Typha sp.)
Scale in Feet
300
0
300
600

TABLE 13. Some Attributes of Aquatic Macrophytes Found in Lake Shakamak

SPECIES	Nuisance[1]	Waterfowl Food Value[2]	Positive Aesthetic Value
Najas flexillis	L	E	
Ceratophyllum demer	R	S-F	
Myriophyllum spp.	R	S-F	
Potenderia cordata		S-F	X
Nymphaea odorata	L	S	X
Nuphar spp.	L	F	X
Vallisneria americana	L	E	

[1]L = local nuisance; R = regional nuisance
[2]S = small, F = fair, E = excellent

Source: Nichols (1986)

5.2 PLANKTON

Plankton species in Lake Shakamak were identified for one sample collected on 8/10/88. A five meter vertical tow was made using a plankton net and bucket assembly having a 63μm mesh size. The five meter depth insured that the entire euphotic zone was sampled. The sample was preserved in Lugol's solution and quantified using a Sedgewick-Rafter counting cell under a compound microscope according to a standardized method (Wetzel and Likens, 1979). Prescott (1962) and Whitford and Schumacher (1973) were used to key specimens. Since this was a screening to determine relative plankton abundance, cell densities rather than biovolumes were determined. Results are presented in Table 14.

The genera listed in Table 14 are found in a wide range of aquatic environments, however many are characteristic of eutrophic conditions. *Anabaena* spp., *Aphanizomenon* spp., and *Microcystis* spp. are among the species which can form dense blooms and these along with *Melosira* spp. and *Mougeotia* spp. are common species in over-productive aquatic systems (Prescott, 1962). For this sample, there was a total of over 70,000 phytoplankton cells per liter. This is considered a high density by the Indiana Department of Environmental Management's trophic state index (IDEM, 1986).

There are a number of factors which influence the species composition and abundance of phytoplankton in lakes. These include nutrient availability,

TABLE 14. Plankton Species Composition in Lake Shakamak

Species	Abundance (#/l)
Blue-Green Algae (Phylum: Cyanophyta	
Anabaena	28,349
Aphanizomenon	32,936
Coelospharium[1]	532
Lyngbya	17
Microcystis[1]	432
Oscillatoria	781
Green Algae (Phylum: Chlorophyta)	
Mougeotia	1,562
Zygnema	50
Staurastrum	17
Diatoms (Phylum: Chrysophyta, Class Bacillariophyceae)	
Melosira	5,002
Synedra	631
Dinoflagellates (Phylum: Pyrrophyta)	
Ceratium	482
Rotifers (Phylum: Rotifera)	
Keratella	33
Arthropods (Phylum: Arthropoda	
Daphnia (Order: Cladocera)	9
Copepods (Order: Copepoda)	10
Nauplii	50
Chaoborus (Order: Diptera)	1

[1]Counts represent colonies rather than individual cells.

light, water temperature, and presence of prey species of zooplankton. Vollenweider (1968) indicates that blue-green algae tend to be abundant in lakes where spring time total phosphorus concentrations exceed 10 $\mu g/l$ and total nitrogen exceeds 200 $\mu g/l$. Both of these limits are exceeded in Lake Shakamak. Smith (1983) found that blue-greens dominated in lakes where the epilimnetic N:P ratio falls below 29:1 and rare when the ratio exceeded this value. In Lake Shakamak, epilimnetic N:P ratios were less than 29:1 at times during the summer. Because some blue-green species can fix atmospheric nitrogen, they can out-compete other algal species when N:P ratios are low. The competitive advantage of blue-greens is further enhanced by other adaptations, including: phosphorus storage, buoyancy regulation, tolerance of warm temperatures, and unpalatibility to zooplankton.

5.3 FISHERIES

Fish management work at Lake Shakamak has included fish stocking, size limit restrictions and a series of DNR fisheries surveys from 1963 to 1985 (Andrews, 1985b). The most recent survey report, from which this information was extracted, is included as Appendix A of this report.

The DNR's primary fish management goal at Lake Shakamak is to maintain a quality panfish fishery. Fishing opportunities for large bluegill and redear sunfish are currently very good at the lake. The largemouth bass population has helped achieve this goal by controlling the abundance of small panfish. However, consistent spawning success and a 14-inch minimum size limit on bass have resulted in a build-up of small bass which are competing for food and space. This large increase in bass abundance has resulted in slow growth of individual bass and low numbers of legal fish. To improve the bass fishery, the DNR implemented a 12 to 15 inch slot size limit to allow anglers to harvest bass under 12 inches or over 15 inches.

The fish management report notes that while aquatic macrophytes are not currently hampering Lake Shakamak's fishery, the further spread of spatterdock could become a nuisance to fishing activities.

6.0 WATER AND NUTRIENT BUDGETS

A Geographic Information System (GIS) was used to estimate annual water budgets for each of the three lakes in Shakamak State Park. Additionally, annual external phosphorus loading was estimated for Lake Shakamak.

6.1 METHODS

A data base including the entire Lake Kickapoo watershed was developed. This database included land use/land cover, soil type, and topography. Land use information was obtained from Indiana Department of Transportation aerial photographs taken during 1977 and 1978. Soil type information was obtained from Clay, Green, and Sullivan Counties Soil Surveys. Topographic information was obtained from 7.5 minute USGS topographic maps (Jasonville and Hymera Quadrangles).

Information for each of these three data elements (themes) were digitized and incorporated into the GIS data structure. The GIS software used, IDRISI, is a raster base system. This means that information is stored in rectangular cells of specified dimensions. A grid with 20m x 20m cells was used to store all the information for each theme; land use, soils, and topography. Each theme comprises one layer or map which can be manipulated to generate additional information. A completed GIS file would resemble a piece of graph paper with numbers in each square. The numbers are identifiers and tell the user which land use, soil type, or elevation is at each cell. Maps are generated by assigning colors or shades of gray to each number. Similar numbers, and therefore similar soil types for instance, receive the same color. A cell in row 50 and column 75 on the soil layer represents the same areal land area as a cell with the same coordinates on the land use map and the topographic map. The values of this type of data storage will be demonstrated in the analysis below.

6.2 WATER BUDGET

A water budget is mandatory for any lake water quality assessment. Water budgets are typically derived from a mass balance equation:

$$\Delta V = (P-E) + R + G - S_o$$

ΔV = change in storage volume
$(P-E)$ = net precipitation (precipitation - evaporation)
R = total basin runoff (stream inflow + sheet runoff)
G = net groundwater flow
S_o = surface outflow

All components are typically expressed in volume units such as 10^6 m^3 (one-million cubic meters).

Stream monitoring stations are the best method for determining R and S_o. The net precipitation factor can be obtained from National Oceanic and Atmospheric Administration data. Changes in storage can be measured by a staff gauge in the lake. Groundwater is difficult to measure and is usually assumed to be negligible or it makes up the difference if all other components are available.

There is no stream or dam monitoring in the Lake Shakamak watershed. Values for runoff and outflow therefore must be estimated using models. To simplify matters it was assumed that there was no change in volume over the course of a year and that net groundwater flow was zero. Net precipitation data was available and summarized in the Clay County Soil Survey. An average annual precipitation, as measured between 1955 and 1977 in Terre Haute, Indiana, of 1.32 meters was used. We can rearrange the mass balance equation, given the known precipitation value and the assumptions stated, to get:

$$S_o = (P-E) + R$$

Chow (1964) provides a method for estimating total basin runoff (R):

$$R = cPA$$

where: c = runoff coefficient
P = precipitation, 1.32m
A = basin area, m^2

We used the GIS data base and this equation to estimate R for each watershed. The runoff coefficient (c) represents the percent of rainfall that runs off the land. For example, a c-value of 0.4 means that 40 percent of the precipitation runs off the land. Values have been calculated for various land uses, soil types and topography. For example, steep slopes, impermeable soils and cultivated land are all factors which result in increased runoff and therefore, higher coefficient values. A c-value of 0.45 was applied to urban and residential land uses, 0.5 to agricultural land, 0.4 to forested land, and 0.35 to rangelands or pasture. The GIS assigned these c-values to each of the identifying land use numbers with the associated c-values. The result is a map of c-values for each watershed. The GIS next calculated total area of land with the same c-value. This area is multiplied by the c-value for each area and the annual precipitation (1.32m). The result is a runoff volume attributable to each land use. Precipitation falling directly on the lake or its inflowing streams is given a c-value of 1.0 since all of this water reaches the lake. These are summed and a total basin runoff is calculated for each watershed (Tables 15, 16 and 17).

The hydraulic residence time is the water replacement time, or the time it takes one volume of lake water to be replaced by a like volume of runoff and precipitation. The flushing rate is the inverse of this or the number of lake volumes replaced by water inputs each year. These two parameters are

TABLE 15. Water Budget Estimates for Lake Shakamak.

LAND USE	C-VALUE	AREA (m^2)	PRECIPITATION (m)	RUNOFF (m^3)
Urban	0.45	16,800	1.32	9,979
Residential	0.45	294,000	1.32	174,636
Agricultural	0.50	1,483,000	1.32	978,878
Forested	0.40	1,978,800	1.32	1,044,806
Streams	1.00	38,800	1.32	51,216
Lakes	1.00	238,400	1.32	314,688

Watershed area = 4,049,800 meters^2 — 2,574,203 m^3/yr

Lake Shakamak Volume = 744,000 m^3

Residence Time (Tw) = 0.29 yrs

Flushing Rate (ρ) = 3.46 volumes/yr

Aerial Water Loading = 11.19 m/yr

TABLE 16. Water Budget Estimates for Lake Lenape.

LAND USE	C-VALUE	AREA (m^2)	PRECIPITATION (m)	RUNOFF (m^3)
Commercial	0.45	2,800	1.32	1,663
Residential	0.45	330,400	1.32	196,258
Agricultural	0.50	2,150,000	1.32	1,419,000
Pasture	0.35	171,200	1.32	79,094
Forested	0.40	1,765,600	1.32	932,237
Streams	1.00	61,600	1.32	81,312
Lakes	1.00	198,000	1.32	261,360

Watershed area = 4,679,600 meters^2 — 2,970,924 m^3/yr

Lake Lenape Volume = 604,427 m^3

Residence Time (Tw) = 0.20 yrs

Flushing Rate (ρ) = 4.92 volumes/yr

Aerial Water Loading = 14.85 m/yr

TABLE 17. Water Budget Estimates for Lake Kickapoo.

LAND USE	C-VALUE	AREA[a] (m^2)	PRECIPITATION (m)	RUNOFF (m^3)
Commercial	0.45	22,400	1.32	13,306
Residential	0.45	30,000	1.32	17,820
Agricultural	0.50	818,400	1.32	540,144
Pasture	0.35	699,200	1.32	323,030
Forested	0.40	1,471,600	1.32	777,005
Streams	1.00	31,200	1.32	41,184
Lakes	1.00	917,600	1.32	1,211,232

Watershed area = 3,990,400 meters^2 — 2,923,721 m^3/yr

Lake Kickapoo Volume = 8,819,708 m^3

Shakamak outflow	2,574,203 m^3/yr
Lenape outflow	2,970,924 m^3/yr
Total water loading	8,468,848 m^3/yr

Residence Time (Tw) = 1.04 yrs

Flushing Rate (ρ) = 0.96 volumes/yr

Aerial Water Loading = 7.24 m/yr

[a]Excludes Lake Shakamak and Lenape areas which drain into Kickapoo but were accounted for in previous tables.

important to consider in developing management plans. For example, in a lake with a long hydraulic residence time, watershed management techniques can take longer to improve lake water quality than in-lake management techniques since the watershed hydraulic loading is small relative to the lake volume. The effects of reducing watershed nutrient inputs will have little effect until the in-lake nutrients can be diluted and flushed out.

Of the three lakes, Lenape has the shortest hydraulic residence time (0.20 yrs); Shakamak's is only slightly longer while Lake Kickapoo's residence time (1.04 yrs) is five times longer. While it is difficult to generalize, long hydraulic residence times are often considered to be one year or longer.

6.3 PHOSPHORUS MODELING

Simpson and Reckhow (1979) developed an empirical model which is used to predict the average in-lake phosphorus concentration during the growing season, given external phosphorus loading estimates and aerial water loading. This model was based largely on Vollenweider's (1968; 1975) work.

The model is as follows:

$$P = \frac{L}{11.6 + 1.2\ qs}$$

where: P = in-lake phosphorus concentration (mg/l)
L = total aerial phosphorus loading ($g/m^2/yr$)
qs = aerial water loading (m/yr)

Areal water loading (qs) is the total basin runoff (calculated above) divided by the area of the lake. Areal phosphorus loading is determined by summing the products of land use area and P export coefficients for each land use. Export coefficients have been derived for watersheds of different land use, soils, sizes, and topographic characteristics (Reckhow et al., 1980). We selected coefficients representative of the soils and topography for each land use category in Lake Shakamak's watershed. These were adjusted for cell area and assigned to cells with the appropriate land use, using the GIS data base. The result was a map of phosphorus export coefficients. Initial coefficients used were 200 $kgP/10^6m^2$ for agriculture and residential land uses, and 80 $kgP/10^6m^2$ for forest areas. These converted to 80 gP/cell and 32 gP/cell to account for the 400 m^2 GIS cell area.

The total number of cells were counted with the GIS and multiplied by the export coefficient associated with each area to get a total phosphorus load for the watershed (Table 18). Estimated phosphorus loading from precipitation falling directly on the lake surface (13,588 g/yr) was added to this. This sum was divided by the lake surface area to obtain aerial phosphorus loading, L, ($g/m^2/yr$). This value was used in the model above and an in-lake phosphorus concentration of 88.9 μg/l was estimated. This was slightly higher than observed spring values.

Reckhow et. al. (1980) suggest that the distance from a lake or tributary and slope may effect how much phosphorus exported from an area in the watershed actually reaches the lake. We used the GIS data base to model these possible effects. First, distance on each cell in the watershed to the nearest part of the lake or a tributary was calculated. A linear scale of 1 to 0 was then applied. A value of 1.0 was assigned to the cells closest to water and values of 0 for the cells farthest away. The values of these cells were multiplied by the values of the export coefficients for the same cells. Therefore, a cell adjacent to the lake with a export value of 80 kgP/ha was multiplied by 1 and remained the same. Whereas, a cell in the middle of the watershed with the same land use and export value of 80 was multiplied by 0.5 and the resulting export value was 40. The results of this analysis are presented in Table 19. This simple distance "filter" changed the in-lake phosphorus concentration estimate to 63.8μg/l.

TABLE 18. Phosphorus Export Coefficients, Total Areal Loading (L), and In-Lake Phosphorus Estimation with Raw Export Values Only.

Coefficient Values (g/400m2)	Number of Cells (400m2)	Loading (gms)
32	4,947	158,304
80	4,483	358,640
	Total P from the watershed =	516,944 g/yr
	Total P from precipitation =	13,588 g/yr
		530,532 g/yr

$$\text{Aerial L} = \frac{530{,}532}{238{,}400}\ \frac{\text{g/yr}}{\text{m2}} = 2.22539\ \text{g/m2/yr}$$

$$[P] = 0.0889\ \text{mg P/l}$$

A similar procedure for the slope factor was applied to the results of the distance analysis. Cells with steep slopes were assigned values of 1 and cells with zero slopes were assigned values of 0. Cells having intermediate slopes were assigned intermediate slope filter values. The values in these cells were multiplied by the values in the distance filtered cells. The results are presented in Table 20. The in-lake phosphorus concentration was predicted to be 18.3 μg/l. This is close to observed spring concentrations (13.9 μg/l in April and 29.8 μg/l in May). A map depicting possible areas of high phosphorus loading was developed and may prove useful in management of the watershed (Figure 21).

This analysis using GIS breaks new ground in phosphorus modeling. While this is our best estimate of phosphorus loading to Lake Shakamak, care must be taken in applying these numbers. For example, linear filters may not reflect the actual influence of either slope or distance on phosphorus transport. It was simple to apply however, and future research may reveal that an alternative scale is more appropriate. Additionally, soil characteristics, such as cation exchange capacity, iron and aluminum content, etc., are important factors affecting soluble phosphorus mobility. This could not be accounted for with the present model. Without complete soil data, modeling these effects is impossible. Finally, it was assumed that once phosphorus entered a tributary it automatically reached the lake. Studies on nutrient spiralling in streams has demonstrated that this is not necessarily the case. Accounting for these factors provides modeling challenges for the future.

TABLE 19. Phosphorus Export Coefficients, Total Areal Loading (L), and In-Lake Phosphorus Estimation with a Distance Filter Applied to Raw Export Values

Coefficient Values ($g/400m^2$)	Number of Cells ($400m^2$)	Loading (gms)
18	20	360
20	50	1,000
22	82	1,804
24	116	2,784
26	404	10,504
28	53	1,484
30	1,978	59,340
32	1,144	36,608
40	816	32,640
45	118	5,310
50	500	25,000
55	746	41,030
60	859	51,540
65	865	56,225
70	378	26,460
75	196	14,700
80	5	400

Total P from the watershed = 367,189 g/yr
Total P from precipitation = 13,588 g/yr

Total P loading = 380,777 g/yr

$$\text{Aerial L} = \frac{380{,}777 \text{ g/yr}}{238{,}400 \text{ m}^2}$$

$$[P] = 0.0638 \text{ mg P/l}$$

TABLE 20. Phosphorus Export Coefficients, Total Areal Loading (L), and In-Lake Phosphorus Estimation with Distance and Slope Filters to Raw Export Values

Coefficient Values (g/400m2)	Number of Cells (400m2)	Loading (gms)
3	54	162
4	412	1,648
5	1,613	8,065
6	28	168
7	477	3,339
8	1,753	14,024
9	732	6,588
10	927	9,270
11	826	9,086
12	619	7,428
13	228	2,964
14	144	2,016
15	324	4,860
16	288	4,608
17	104	1,768
18	134	2,412
19	157	2,983
20	132	2,640
21	72	1,512
22	69	1,518
23	70	1,610
24	64	1,536
25	60	1,500
27	75	2,025
29	32	928
30	2	60
31	21	651
32	6	192
33	2	66
35	3	105
38	1	38
40	1	40

Total P from the watershed = 95,810 g/yr
Total P from precipitation = 13,588 g/yr

109,398

$$\text{Aerial L} = \frac{109,398 \text{ g/yr}}{238,400 \text{ m}^2} = 0.4589 \text{ g/m}^2\text{/yr}$$

[P] = 0.0183 mg P/l

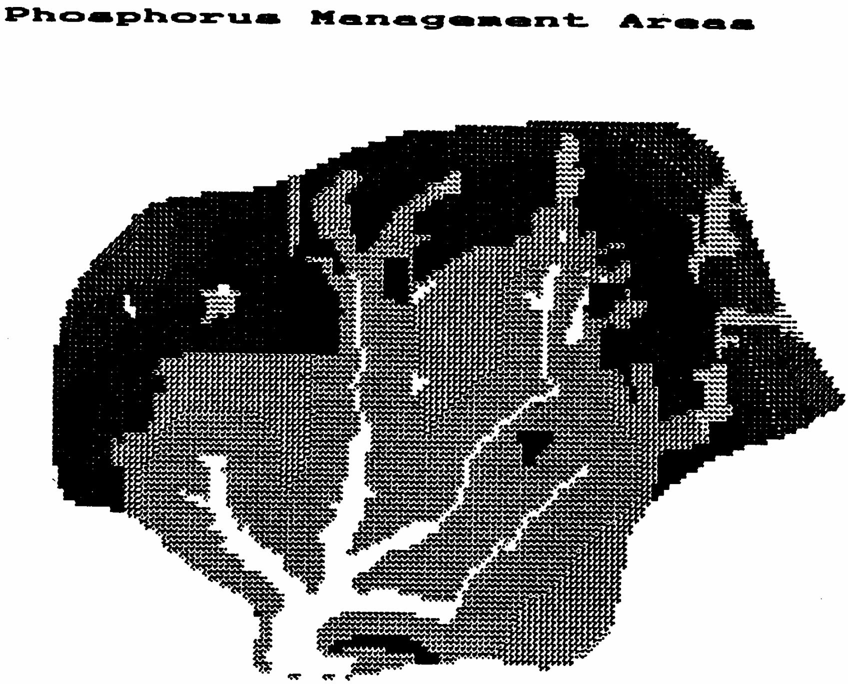


Figure 21. Phosphorus export with distance and slope filters applied. Lighter shading identifies areas where land use, slope and distance combine to create a higher potential for phosphorus export. Unshaded areas represent water.

6.4 INTERNAL PHOSPHORUS LOADING

The in-lake phosphorus concentration estimated by the model significantly underestimates summertime phosphorus concentrations, which exceeded 900 $\mu g/l$ in Lake Shakamak's epilimnion. The model is based on external sources of phosphorus loading and does not account for internal recycling of phosphorus from the sediments. The extensive anoxic zone and the large increase in hypolimnetic SRP concentrations suggest that internal phosphorus loading may be significant in Lake Shakamak.

Internal phosphorus loading (L_L) can be estimated by comparing external loading (L_E) as predicted by the model with total loading (L_T) as determined from measured in-lake phosphorus concentrations by the following relationship:

$$L_I = L_T - L_E$$

For example, by using the average summertime epilimnetic total phosphorus concentration ($367\mu g/l$) for [P] in Simpson and Reckhow's (1979) model (Section 6.3), we can solve for L_T. This yields an L_T of $9.19 g/m^2/yr$. Thus,

$$L_I = 9.19 g/m^2/yr - 0.46 g/m^2/yr = 8.73 g/m^2/yr$$

From this calculation, internal phosphorus loading accounts for 95 percent of total summertime phosphorus loading to Lake Shakamak.

As mentioned in Section 3.2.1, internal phosphorus loading is caused by the release of phosphorus from the sediments under reducing conditions in the anoxic hypolimnion. In Twin Lakes, Ohio, internal phosphorus loading was estimated to be 65 to 105 percent of total phosphorus loading (Cooke et. al., 1977). While the estimate for Lake Shakamak falls within this range, the rapid increase and variability of phosphorus concentrations in Lake Shakamak suggest that other factors may be involved. The drought and extreme heat during the summer may have aggravated this process or there may be an unaccounted for source of phosphorus to Lake Shakamak.

There are two potential point sources of phosphorus to Lake Shakamak that could not be investigated during this project. An inverted syphon wastewater line from the group camp area runs beneath lobe #1 of the lake. Exfiltration from this line, which is slightly under pressure, could introduce nutrients to the lake. In addition, several of the family cabins on the west side of the lake discharge gray water from lavatories to sumps in the ground. Leaking or overflowing sumps may also be a source of nutrients to the lake.

6.5 TROPHIC STATUS

Vollenweider (1975) quantitatively defined the relationship between nutrient loading and trophic response and developed a relationship based on these components. The relationship relates total phosphorus loading as a function of mean depth (z), flushing rate (ρ) and phosphorus loading. External areal loading (L_E) from Table 20 and total loading (L_T) are plotted on Vollenweider's graph in Figure 22. As seen from this, external phosphorus loading to

Lake Shakamak falls between acceptable and excessive loading guidelines while total loading and internal loading fall well into the eutrophic range.

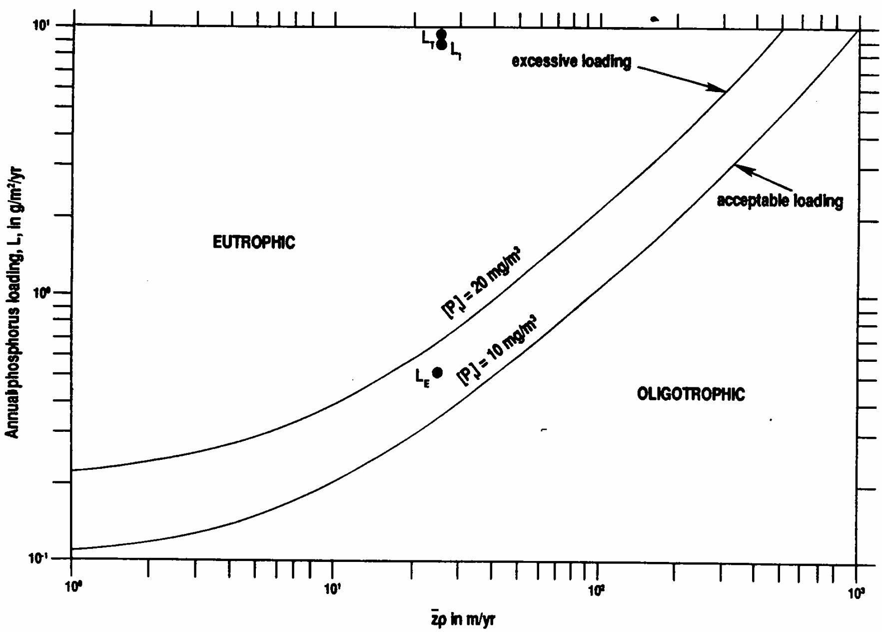


Figure 22. Nutrient loading/lake trophic condition for total loading (L_T), external loading (L_E) and internal loading (L_I) to Lake Shakamak, after Vollenweider (1975).

7.0 MANAGEMENT OPTIONS

7.1 APPROACH

Any program to improve the water quality of Lake Shakamak must address the major problems affecting the lake. In summary, these are:

1. Seasonally high in-lake phosphorus concentrations which stimulate excessive phytoplankton production.

2. Seasonal dissolved oxygen depletion affecting a substantial volume of the lake.

3. Extensive rooted aquatic macrophyte growth which covers nearly one-half of the lake's surface area.

4. Sedimentation, particularly at the upper ends of the lake and along the inlet streams.

It must be remembered that any in-lake management efforts will be successful only with concurrent management of watershed sources of pollutants. Without watershed management, water quality improvements in Lake Shakamak will be short-lived.

7.2 WATERSHED MANAGEMENT

The goals of watershed management at Lake Shakamak are to reduce nutrient and sediment loads in the lake. While external phosphorus loading is small relative to internal loading, it is significant enough to be a concern. Sedimentation at the check dams and culverts proves that soil erosion in the watershed should be reduced through management. While a portion of the sediment and phosphorus load carried by streams is from natural sources, human activities are responsible for the largest percentage of stream loading. Many studies have concluded that nitrogen and phosphorus loadings to streams increase as the proportion of land in agricultural and urban land uses increases (Omernick et al., 1976; Reckhow et al., 1980).

7.2.1 <u>Land Use Practices</u>

Agricultural practices that reduce erosion and runoff from the land include:

1. Reduced or no-till plowing.
2. Contour cropping.
3. Grassed waterways.
4. Manure management.
5. Spring rather than fall cultivation.
6. Vegetated buffer strips along streams.

The need for these management practices is evident at selected locations in the watershed. For example, fall plowing of corn stalk rubble leaves the soil unprotected throughout the winter. We observed this practice in several areas.

The federal Soil Conservation Service (SCS) and the county Soil and Water Conservation Districts should be contacted and asked to provide assistance. These agencies can assess watershed treatment needs and provide technical, cost-sharing, and credit assistance for land treatment, structural controls, and nonstructural measures. Land areas identified in Figures 20 and 21 should be targeted.

The present goal of the state Division of Soil Conservation's "T by 2000" program is to reduce erosion on each acre of land to its tolerable limit or T. This is the maximum level at which soil loss can occur without impairing crop productivity. T is approximately 3-5 tons/acre/yr for agricultural soils. Since the estimated average soil loss for Lake Shakamak's watershed (2.54 tons/acre/yr) is already below T, there may be little basin-wide need for assistance except for localized areas.

Erosion control practices for construction sites include:

1. Siltation fences.
2. Straw bale sediment traps in drainageways.
3. Sedimentation basins.
4. Hydroseeding and mulching to quickly re-establish a vegetated cover.
5. Grassed waterways.

These practices can be used to prevent soil erosion and transport whenever the vegetation cover is disturbed during construction of buildings, roads, trails, etc. For small disturbances, redirecting runoff toward stabilized drainageways and placing temporary straw bales in the drainageway can control soil losses. For larger disturbances, siltation fences or sedimentation basins may be required.

7.2.2 Sediment Traps

The check dams installed in the 1930's did their job while they were functional. Time and lack of maintenance have made them non-functional. This has allowed sediments to breach the dams, fill the culverts and reach the lake. The existing check dams should be dug out and repaired. Filled culverts should be cleaned out, damaged culverts replaced, and eroded culverts repaired. Where water is undercutting the culverts, cement facing around the culvert opening may be the only option. The steep road banks under which the culverts run are very susceptible to erosion due to their slope. If regrading the slopes is not feasible, stone rip-rap with underlying filter cloth should be used to repair and stabilize eroded areas. Table 21 and Figure 18 identify the problem areas needing attention.

TABLE 21. Check Dam and Culvert Management Needs

Site 1.	Clean out filled in culvert and check dam. Repair check dam as needed.
Site 2.	Clean out check dam. Remove sediment deposits at outlet of culvert to provide passage of water.
Site 3.	Clean out check dam. Repair dam and washouts. Dam may need extending to west. Remove sediment deposits from stream immediately below dam. Repair eroded drainageway with rip-rap or suitable material.
Site 4.	Culvert is being undercut on upstream side and is crushed on lake side -- needs replacement. Consider adding check dam at this site.
Site 5.	Culvert is being undercut -- may require cement facing or reinforcement. Stone wall on lake side of road cut needs repair.
Site 6.	New culvert is showing signs of erosion damage on upstream side -- may require rip-rap or cement facing. Large cement blocks below culvert should be removed from streambed.
Site 7.	Stabilize streambank opposite culvert outfall to prevent erosion.

The designed use for check dams (dry sedimentation basins) is to provide temporary storage and gradual release of peak discharges in streams. During this process, the heavy suspended material, or bedload, settles out offering some sediment detention as well. However, if the area behind the check dam drys out between runoff events, the next high discharge can scour out the previously deposited sediments.

Despite this, the check dams are the most cost-effective sediment control for Lake Shakamak. However, by their very nature they require routine maintenance. The Division of State Parks must be prepared to inspect annually these structures and make repairs as needed. Sedimentation basins should be cleaned out every year in the autumn to remove accumulated sediments before a "flushing" spring rain occurs.

The rather low sedimentation rate in Lake Shakamak suggests that the combination of watershed land use management and dry sedimentation basins will be adequate to reduce sedimentation even further. If, however, the Division of State Parks feels additional control is needed, more sophisticated wet sedimentation basins are an option. Wet sedimentation basins are designed to allow permanent settling of sediments before they can enter a lake. If well-designed and properly maintained, suspended solids removal of 70 to 90 percent are possible (Pitt, 1985). Some design features of these basins are illustrated in Figure 23. As a general rule, wet detention basins should have a surface area approximately 0.5% of the watershed. For Lake Shakamak's subwatersheds, wet sedimentation basins of 2.5 ha (1 acre) each would be required. These structures would have to be carefully engineered and costs are obviously much higher than repair and maintenance of the current check dams.

7.2.3 Nutrient Traps

Recently efforts have been made in Indiana to use constructed and reconstructed wetlands as nutrient traps in streams prior to their discharge into lakes. Crisman (1989) reports that a one-year old constructed wetland along Wilson's Ditch at Lake Maxinkuckee was trapping 80-90% of the phosphorus load in the stream. Such a system could provide additional management of watershed sources of phosphorus currently affecting the lakes at Shakamak State Park. The applicability of constructed wetland phosphorus filters to Lake Shakamak would require additional study of actual stream nutrient loads.

7.3 IN-LAKE MANAGEMENT

7.3.1 Sediments

The rather low sedimentation rate and expected effectiveness of the repaired check dams suggest that no in-lake management of sediments is required other than maintaining the rooted aquatic vegetation beds at the mouths of Lake Shakamak's inlets. The vegetation acts to filter out suspended sediment remaining in the streams, preventing them from moving further into the lake.

Sediment accumulations to date in the lake do not appear to hamper any in-lake uses. The thickest deposit of sediments in Lake Shakamak is just 0.78 meters and the average is just 0.34 meters (about 1.1 feet). The primary option for deepening lakes is dredging and this is just not warranted in Lake Shakamak at this time.

7.3.2 Phosphorus

The extremely high phosphorus concentrations in Lake Shakamak demand management. The goal of phosphorus management is to reduce summertime concentrations below that required for excessive algal growth. The nutrient budget suggests that the watershed sources included in the model are a small percentage of total phosphorus loading to Lake Shakamak. It follows from this that the bulk of loading must come from internal sources. However, the potential loading from a leaking sewer line or from gray water discharges from the family cabins should be examined more fully.

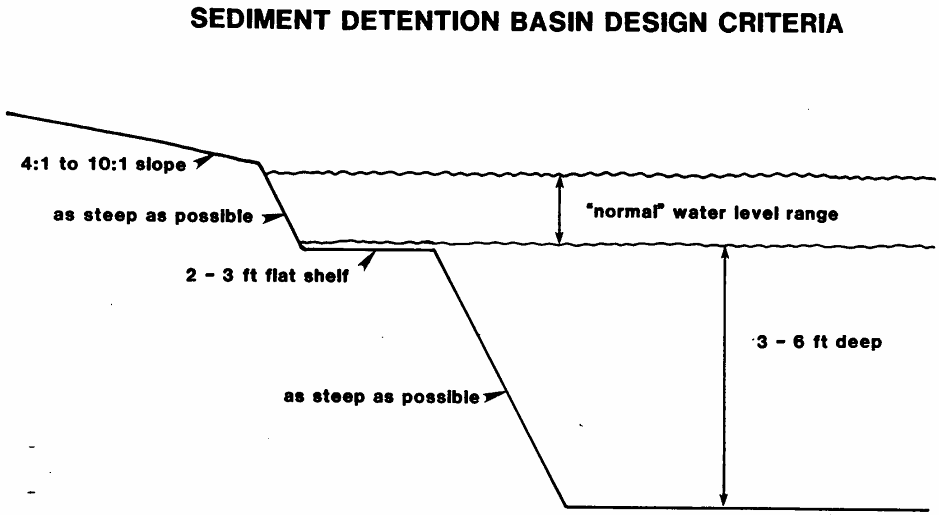


Figure 23. Design features of wet sediment detention basins.

The greatest source of phosphorus to Lake Shakamak is the sediments. There are two approaches that can be used to prevent internal phosphorus release -- "sealing" the sediments by nutrient inactivation or preventing the reducing conditions that promote phosphorus release, by aerating the hypolimnion.

Nutrient Precipitation/Inactivation

Treatment of lakes with aluminum sulfate (alum) ($Al_2(SO_4)_3 \cdot 14H_2O$) or sodium aluminate ($Na_2Al_2O_4$) can be successful in removing phosphorus from the water column and for controlling its release from sediments. This chemical process has been used for many years in the treatment of drinking water and wastewater. Aluminum hydroxide ($Al(OH)_3$) has a high capacity for removing dissolved and suspended phosphorus materials under conditions that are common to lakes. Phosphorus removal can occur by coagulation and entrapment of phosphorus in the resulting aluminum hydroxide floc, precipitation of aluminum phosphate ($AlPO_4$), or by sorption of phosphorus on the surface of the floc. If phosphorus is to be removed from the water column, the alum is surface applied. If control of phosphorus release from sediments is desired, sufficient alum is applied, either at the surface or at the sediment water interface, to create an aluminum hydroxide flox barrier on top of the sediments. Soluble phosphorus escaping the sediments is then intercepted by the floc barrier.

Use in Other Lakes. Alum flocs have been effective for over six years in preventing sediment phosphorus release in Dollar Lake, Ohio and for four years in Long Lake, Washington (Cooke, et. al., 1982; Welch et. al., 1986). In Dollar Lake, 83 percent of water column total phosphorus was removed. At Horseshoe Lake, WI, the first lake in the U.S. treated with alum, phosphorus was controlled by alum for more than 12 years (Garrison and Knauer, 1984). Likewise, an alum treatment at Snake Lake was effective for over 10 years. Alum's effectiveness in Pickeral Lake, Wisconsin was less than one year because the floc shifted along the lake bottom and settled in the deepest part of the lake (Garrison and Knauer, 1984). The effectiveness of alum treatment is often reduced due to continued deposition of phosphorus-enriched sediments which cover the floc and provide new sources of sediment phosphorus.

Adverse Effects. Potential adverse effects of alum treatments include:

1. Short term turbidity due to floc formation.
2. Decrease in water column pH.
3. Toxicity of aluminum to aquatic organisms.

The addition of aluminum salts to water results in a decrease in pH, particularly in poorly buffered systems. The precipitation reaction using alum neutralizes alkalinity in water by the following reaction:

$$Al^{3+} + 3OH \rightarrow Al(OH)_3$$

For every 1 mg Al/l added to lake water, 5.6mg $CaCO_3$ alkalinity per liter is neutralized. As long as pH remains greater than 6.0, aluminum solubility (and toxicity) is not a problem. Therefore, proper dosing is important in reducing adverse effects.

If pH control is difficult for the prescribed alum dose, sodium aluminate ($Na_2Al_2O_4$) can be used in conjunction with the aluminate reaction adds alkalinity by the following:

$$AlO_2 + 2H_2O \rightarrow Al(OH)_3 + OH^-$$

Assuming complete reaction, a ratio of 3.1:1 of mg Al from aluminate to mg Al from alum will maintain the alkalinity of the water.

Dose Determination. The optimum alum dose is one that produces the largest floc barrier without lowering pH below 6.0. Based on springtime pH and alkalinity values, and using the dose determination method of Kennedy and Cooke (1982), the maximum alum dose for Lake Shakamak is approximately 7 mg Al/l. The dose should be more precisely determined experimentally using a standard jar test, before proceeding with treatment. A jar test can relate phosphorus reduction and pH change to alum dose. If additional Al is needed to achieve greater phosphorus removal rates, sodium aluminate can be used with the alum.

The amount of alum needed to achieve a dose of 7 mg Al/l is difficult to estimate since different manufacturers report different concentrations of Al in alum. Liquid alum is usually rated at 8.3% Al_2O_3 (Kennedy, et al., 1987). If we use this figure, the percent Al by weight is then:

$$(8.3)\left(\frac{2\text{ mol. wt. Al}}{\text{mol. wt. }Al_2O_3}\right) = 8.3\left(\frac{54}{102}\right) = 4.4\%\text{ Al by weight}$$

If we assume a density of liquid alum of 11 lbs/gal at 60°F (Booker Associates, Inc., 1984), then by volume Al content becomes:

$$(4.4\%\text{ Al})\left(\frac{11\text{ lb}}{\text{gal}}\right)\left(\frac{0.454\text{ kg}}{\text{lb}}\right) = 0.22\text{ kg Al/gallon}$$

A dose of 7 mg/l Al will require:

$$\frac{7\text{ mg/l}}{0.044} = 159\text{ mg/l liquid alum}$$

To achieve this concentration in Lake Shakamak's hypolimnion (Vol. = 2.34 x 10^8 l) will require:

$$\left(\frac{159\ \text{mg}}{1}\right)\ (2.34 \times 10^8\ \text{l})\ \left(\frac{\text{kg}}{10^6\ \text{mg}}\right)\ \left(\frac{\text{lb}}{0.454\ \text{kg}}\right)\ \left(\frac{\text{ton}}{2000\ \text{lbs}}\right) = 40.9 \text{ tons liquid alum}$$

Table 22 summarizes characteristics of the aluminum sulfate treatment of Lake Shakamak.

Cost. At current prices of $165 per ton dry weight, chemical costs to treat Lake Shakamak would be $3,273. Application costs may vary depending on whether the Division of State Parks applied the alum or hires a contractor. A general rule of thumb is that application cost is twice that of the alum. For Lake Shakamak then, an estimated application cost is $6,546 and total cost would be $9,819. At Eau Galle Lake, a reservoir in Wisconsin, total treatment costs averaged $553/ha to apply an aluminum dose of 4.5 mg/l (Kennedy et al., 1987). At this rate, it would cost approximately $8,600 to treat Lake Shakamak.

Application. The basic components of an alum application system are illustrated in Figure 24. The manifold system should be set at a predetermined depth in order to discharge the mixture below 3.0 meters for Lake Shakamak. Liquid alum can be pumped directly from a tank truck on shore to a storage tank on the application barge. Buoys should be used to divide up the treatment zones and to guide the application barge.

Aeration

The objectives of aeration are to establish aerobic conditions in the hypolimnion to control phosphorus release from the sediments and to provide increased habitat and food supply for cold-water fish species. Three aeration approaches are possible, 1) artificial circulation, 2) hypolimnetic aeration, and 3) layer aeration.

Artificial Circulation. Artificial circulation is one of the oldest lake management techniques. It has been used for more than 30 years. Artificial circulation involves pumping compressed air through diffusers on the bottom of the lake. As the air bubbles rise, the water on the bottom of the lake rises and mixes with surface water. Ultimately the entire lake is continually mixed and the lake is destratified. Oxygen is diffused from the water/atmosphere interface and comparatively little oxygen is actually dissolved from the bubbles. Lorezen and Fast (1977) suggest that to provide adequate water movement to maintain circulation 9.2 m^3/min of air must be pumped for each 1 X 10^6 m^2 lake surface area. Lake Shakamak therefore, would require pumps to move 2.1 m^3/min of air to maintain circulation.

TABLE 22. Characteristics of the Aluminum Sulfate Treatment of Lake Shakamak

Application depth	3 meters
Treatment area	11.5 hectares
Total lake area	40 hectares
Treatment volume	234,000 m^3
Total lake volume	743,800 m^3
Total aluminum dose	1,638 kilograms
Areal aluminum dose	14.2 $grams/m^2$
Volumetric aluminum dose	7 mg/l

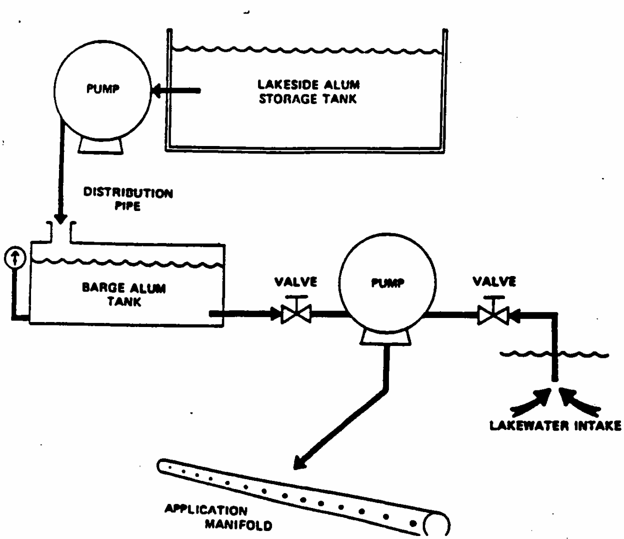


Figure 24. Basic components of an alum application system (from Cooke et. al., 1986).

Destratification resulting from this method can have negative impacts on lake water quality. For example, because the lake is completely mixed, the overall heat content of the water is increased. Bottom waters can be heated 10 to 15°C while surface waters are cooled only slightly (Pastorek et al., 1981). In addition, artificial circulation can increase the turbidity and oxygen demand by resuspending flocculent sediment material.

Hypolimnetic Aeration. Hypolimnetic aeration increases the oxygen content of the hypolimnion without disturbing thermal stratification. A box on the surface of the water has two or more tubes extending to the lake bottom. Within the bottom of the intake tube is a bubbler similar to one for aeration/circulation (Figure 24). Air bubbles rise to the box on the surface, pulling hypolimnetic water with it. As the water and air mixture rises, oxygen is dissolved into the water. Once at the surface, further oxygen diffusion from the atmosphere can occur. Because of the temperature and density differences between surface water and the hypolimnetic water in the box, the denser hypolimnetic water flows down the other tube back to the hypolimnion. This type of system only operates during stratified periods.

Ashley (1985) describes a method for sizing such a system. It is a ten step process based on volume of the hypolimnion, rate of oxygen depletion, depth of hypolimnion, and air to water mixing efficiencies.

We have used this to design a hypolimnetic aeration system for Lake Shakamak below three meters. The volume of the lake below three meters is 234,000 m^3. The maximum rate of oxygen depletion between April and June is 0.26 mg/l/day. To account for a possible increase in oxygen demand due to limited resuspension of sediments during the procedure, we multiplied this rate by two, obtaining an oxygen depletion rate of 0.52 mg/l/day. Multiplying this by hypolimnetic volume gives a 121 kg/day oxygen consumption rate. This is the amount of oxygen a system must dissolve each day to maintain oxic conditions in the hypolimnion of Lake Shakamak.

With an average aerator input rate of 4.6 mg/l, we calculate the rate of water flow needed at 0.306 m^3/sec. This would require input tubes to be at least 0.57 meters in diameter. The density of air water mixture is 949.37 assuming a treatment depth of 4.5 meters. Air flow required is 1.48 m^3/min which requires a pump pressure of 2.55 kg/cm^2. A surface box 1.8 meters wide x 0.9 meters wide x 0.67 meters high is needed. The floatation device for the box would need to support 210.6 kg plus the weight of the box material and the input and output tubes. Table 23 summarizes characteristics of a full lift hypolimnetic aeration treatment for Lake Shakamak.

Costs for hypolimnetic aerators vary widely. The devices may be fabricated and constructed on-site or a patented, pre-constructed system could be purchased. For one system, average operating costs at a power rate of $0.07 kw/m was $0.056/kg O_2/day (Cooke et al., 1986). At this rate, annual operating costs for Lake Shakamak would be $2,435 per year.

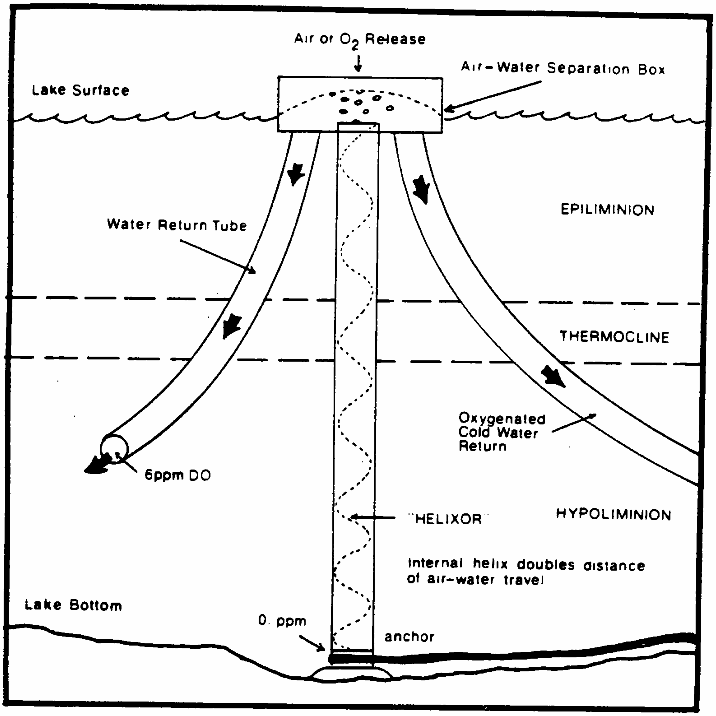


Figure 24. A simple hypolimnetic aeration design.
Source: Born (1974)

TABLE 23. Characteristics of the Full Lift Hypolimnetic Aeration Treatment for Lake Shakamak

Hypolimnetic volume	234,000 m^3
Total lake volume	743,800 m^3
Adjusted oxygen depletion rate	0.52 mg/l/day
Hypolimnetic oxygen consumption rate	121 kg/day
Air flow required	1.48 m^3/day

In reviewing hypolimnetic aeration case studies, Cooke et. al. (1986) report that 12 of 13 lakes had hypolimnetic D.O. increases to at least 7 mg/l during treatment. This created better fish and zooplankton habitat. Some lakes had hypolimnetic phosphorus concentrations decrease by up to 55 percent while others had smaller reductions. In several cases, reductions in phosphorus concentrations due to aeration were compromised by continued external loading of phosphorus.

We must point out that the beneficial effects of aeration last only as long as the aeration units are operating. If the use of aeration is discontinued, the lake can quickly revert back to pre-aeration conditions.

Layer Aeration. A third aeration method is called layer aeration and is described by Kortmann et al. (1988). This method involves mixing metalimnetic waters to create a smaller hypolimnion and therefore a smaller volume of water needs treatment. It simply takes water from the top and bottom of the thermocline, mixes it and returns it to the middle of the thermocline. Once this metalimnetic layer is established, hypolimnetic aeration proceeds as described above. By reducing the volume of water being treated, costs are generally cheaper for this system than for hypolimnetic aeration alone.

7.3.3 Macrophyte Management

The key to successful macrophyte management is a sound management plan. A sound plan is built on four principles (Nichols et al., 1988):

1. Define the problem.
2. Understand plant ecology.
3. Consider all techniques.
4. Monitor the results.

By following these principles, the lake manager will control only those species and areas that require control and will be able to document which techniques either worked or didn't work.

Although aquatic macrophytes cover nearly 50 percent of Lake Shakamak, their coverage does not appear to be increasing. We have already described the benefits and problems associated with aquatic macrophytes. The decision whether to manage or reduce the coverage of macrophytes in the lake depends on the extent to which the macrophytes interfere with lake uses. It was not apparent to us that the macrophytes were interfering significantly with lake uses. Selective management of particular species or of species in particular areas is all that is likely needed at this time.

Of the available macrophyte control techniques, harvesting, chemicals, screens, and water drawdown are considered here. Some of these techniques are species specific. See Table 24 for an overview.

Harvesting. Aquatic plant harvesting can be accomplished by large mechanical harvesting machines, hand cutters, or manual pulling. In addition to removing unwanted plant biomass from the surface waters, harvesting also stresses some aquatic plants, reducing their vigor. Cutting the plants close to their roots is the most stressful to them and two or more harvests per year, especially a late season harvest, can provide residual control the following season.

Regardless of the harvesting technique used, the cut plant biomass must be collected and removed from the water. Harvested plant material quickly releases stored phosphorus and nitrogen as it begins to decay, and decaying plant biomass consumes oxygen. Thus, the removal of harvested biomass removes both mutrients and biochemical oxygen demand (BOD) from the lake.

A reasonable approach would be to control macrophytes in selected areas, such as the boat launch and around the beach and piers. Swaths could also be opened through the dense macrophyte stands to provide additional boat access for fishermen and access to the family cabins. The Division of Fish and Wildlife should be consulted regarding this. Diversity is the key to balancing the positive attributes and minimizing negative attributes of aquatic macrophytes. At present there is a reasonable diversity of aquatic macrophytes in Lake Shakamak. If monotypic stands of less desirable species become dominant, selective harvesting of specific species would be warranted.

The small, macrophyte harvester beached near the boat launch should be more than adequate to carry out the limited harvesting we propose. However, any plant biomass cut must be collected and removed from the lake. Rake attachments are available from manufacturers to assist in gathering cut plants. Cut materials should be piled on land to dry at a location where their nutrients will not drain back into the lake. Dried aquatic plant material is a great soil additive and if the park cannot use it, local citizens will likely be happy to take it away.

There are a number of hand harvesters currently on the market that are easy and effective to use in small areas where a mechanical harvester cannot gain access. Figure 26 illustrates one such tool.

Herbicides. Chemical herbicides can be used selectively to control aquatic macrophytes because plants differ in susceptibility to herbicides. For example, the herbicide Endothal is effective against coontail (Ceratophyllum

TABLE 24. Species Selective Control Methods
(from: Nichols, 1986)

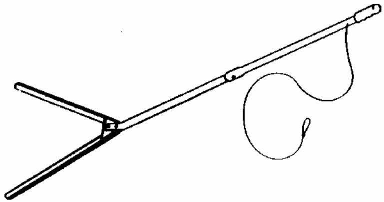
	DRAWDOWN[1]		HERBICIDE[2]			PROPAGATION[3] METHOD
	INCREASE	DECREASE	ENDOTHAL	DIQUAT	2,4-D	
Emergent species						
Acorus calamus			NC	NC	C	R
Glyceria borealis	W		NC	C	NC	
Leersia oryzoides	B					
Pontederia cordata		W				P
Sagittaria spp.		W	NC	NC	C	T
Scirpus cyperinus						R
Scirpus validus	W		NC	NC	C	R
Sparganium chlorocarpum			C	NC	NC	R
Typha latifolia	W		NC	C	CC	R
Zizania aquatica						S
Floating-leaved species						
Brasenia schreberi		B	NC	NC	C	
Lemna minor	S		NC	C	NC	P
Nelumbo lutea		W	NC	NC	CC	S
Nuphar spp.		W	NC	NC	C	
Nymphaea odorata		W	NC	NC	CC	T
Nymphaea tuberosa		W	NC	NC	CC	T
Polygonum coccineum	W		NC	NC	C	
Polygonum natans	W		NC	NC	C	
Submerged species						
Ceratophyllum demersum			C	C	C	P
Chara vulgaris		W	Controlled with copper compounds			P
Eleocharis acicularis						
Elodea canadensis			CC	C	NC	P
Heteranthera spp.			C	C	NC	
Myriophyllum spp.		W	CC	C		
Najas flexilis	B		CC	C	NC	P
Najas guadalupensis			CC	C	NC	
P. crispus			C	C	NC	
P. diversifolius			C	NC	NC	
P. epihydrus	W					
P. foliosus			C	C	NC	
P. gramineus	W					
P. natans				C	C	NC
P. nodosus						R
P. pectinatus			C	C	NC	T,S
P. pusillus			C	C	NC	
P. richardsonii	W		C	C	NC	
P. robbinsii		W				
P. zosteriformes		W	C	NC	NC	
Ranunculus spp.			NC	C	CC	
Ruppia sp.			NC	C	NC	P
Utricularia vulgaris		W	NC	C	NC	
Vallisneria americana			CC	NC	NC	T,S
Zanichellia sp.			C	NC	NC	

[1] Cooke, 1980. Plants increase or decrease with W = winter drawdown, S = summer drawdown, B = both summer and winter drawdown.
[2] Binning et al. n.d. C = controlled, NC = not controlled, CC = conditionally controlled.
[3] Lemberger, 1984. R = roots, T = tubers, S = seed, P = plants.

AQUA WEED CUTTER

T.M.

PATENT PENDING



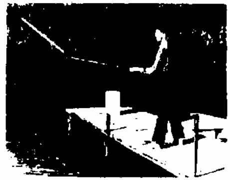
THROW IT OUT - PULL IT IN

The *Aqua Weed Cutter* is easy to use. Just throw the *Aqua Weed Cutter* from shoreline, pier or boat and pull in slowly using short jerky strokes. Underwater weeds pop up to the surface like a cork. When used regularly the *Aqua Weed Cutter* will keep beaches, swimming areas, boat slips, piers, etc., free of weeds.

No need for expensive and potentially harmful chemicals. A one time application of chemicals will pay for the *Aqua Weed Cutter* which with proper care and use can be used for many years.

The *Aqua Weed Cutter* can be used about 3 weeks after the ice melts and whenever weeds begin to reappear.

USE FROM PIER



The *Aqua Weed Cutter* cuts a 52" path through any weeds growing on the bottom of lakes or ponds.

USE FROM SHORE

Just throw the *Aqua Weed Cutter* from shore and keep swimming areas weed free for continual enjoyable use.

Figure 26. Example of an aquatic macrophyte hand harvester for small areas.

demersum) but not against spatterdock (Nuphar variegatum) (Table 24). Unfortunately, herbicides may adversely affect non-target organisms and may require water use restrictions following treatment.

Screening. In small areas around docks, piers, and the beach, bottom screening material has been effective in restricting macrophyte growth. Non-corrosive mesh screening, under a number of product names, has been tested by the Wisconsin Department of Natural Resources and such screens have been used on lakes and ponds in 15 states (Engel, 1985). When rolled onto a lake bed in spring or draped over plants in the summer, the weighted screens reduce sunlight and hasten decomposition of underlying vegetation (Figure 27). Shorelines, pier areas and boating lanes can remain free of vegetation all summer if screens are used. The screens are easily removed in the fall for cleaning and can be reused the following years. Since screening material is rather expensive ($140 per 7' x 100' roll) it is most cost-effectively used in small areas.

Drawdown. Water level drawdown during the winter months can help control aquatic macrophytes in the nearshore areas if the sediments are able to dry out and freeze. Exposure and dessication followed by freezing, stresses certain macrophyte species and can provide control the following growing season (Table 24). This is a rather inexpensive management technique to implement in lakes having an outlet structure with drawdown capability. However, Lake Shakamak cannot be selectively drawn down so this technique is not a feasible option at this time.

7.4 EXPECTED EFFECTIVENESS

The effectiveness of in-lake management techniques applied at Lake Shakamak could be limited by continued sediment and phosphorus loadings from the watershed. Continued implementation of land use practices and the repair and maintenance of the sediment check dams should be effective in controlling sedimentation and reducing external phosphorus loading below the 0.46 $g/m^2/yr$ rate determined previously.

Nutrient inactivation using alum will have the greatest success in substantially reducing internal recycling of phosphorus in Lake Shakamak. Eliminating this source of phosphorus can bring total phosphorus loading closer to acceptable loading levels (see Figure 22). In so doing, the massive algal blooms, and their associated odors, scums, and unsightliness that have plagued swimmers and other lake users, will also be substantially reduced.

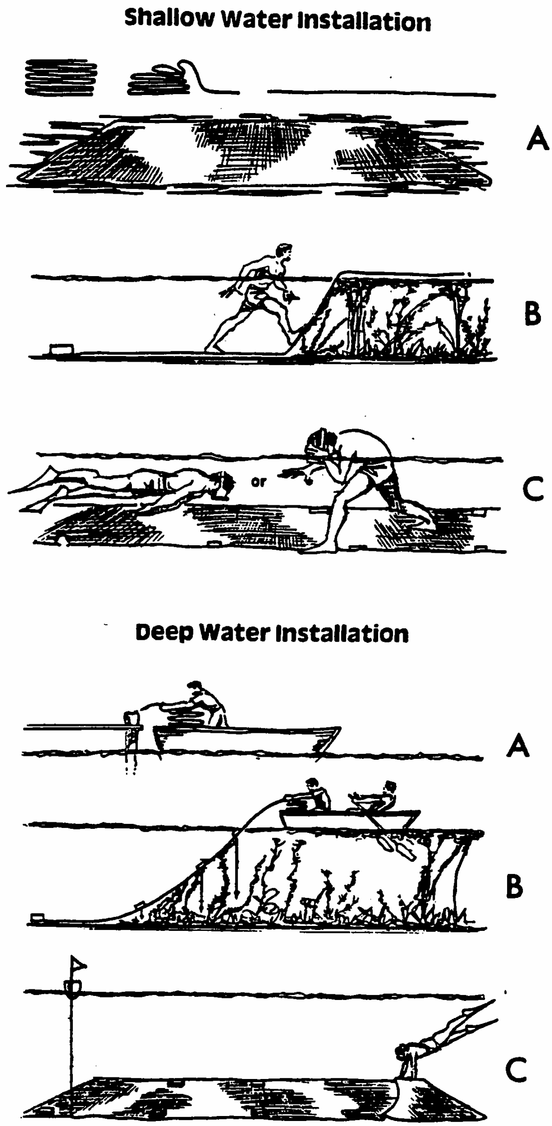


Figure 27. Installation methods for aquatic macrophyte screening. Source: Engel, 1985

8.0 RECOMMENDATIONS

The work plan placed special emphasis on the management of Lake Shakamak. Therefore, the recommendations for Lake Shakamak are more extensively developed than those for lakes Lenape and Kickapoo. The recommendations draw from the management options listed in Section 7.0.

8.1 LAKE SHAKAMAK

8.1.1 Watershed Management

Watershed management is the key to any lake restoration and management program. As stated previously, the goals of watershed management are to reduce nutrient and sediment loads reaching the lake.

Recommendation #1: The Division of State Parks should work cooperatively with the Division of Soil Conservation and the Soil Conservation Service to insure that best management practices (BMPs) are being employed in Lake Shakamak's watershed, especially in the critical areas identified. The Division of Soil Conservations' T by 2000 Program is available to landowners to help implement BMPs.

Recommendation #2: Erosion control practices should be used during any construction activity which disrupts soils within the park. Division of Parks engineers should review erosion control plans prior to the construction of roads, trails, pipelines, buildings, parking lots, etc. in the park.

Recommendation #3: Check dams and culverts should be repaired as described in Table 21. These structures should be inspected and cleaned out at least annually in the fall. Additional cleaning or repairs may be necessary following heavy storms. During inspections, park personnel should also look for areas of streambank erosion that may contribute additional sediment to the lake. Eroded streambanks should be graded to a 2:1 slope or flatter and stabilized with vegetation or rip-rap having a filter cloth underlayment.

Recommendation #4: If the Division of State Parks is interested in using constructed wetlands as phosphorus filters, additional water quality studies must be conducted to characterize the phosphorus load in the inlet streams. The DNR Lake Enhancement Program staff should be consulted for technical assistance as they have experience with constructed wetland filters.

8.1.2 In-Lake Management

Recommendation #5: The wastewater line that runs under Lobe #1 of the lake from the group camp should be tested to determine whether it is leaking. A dye test or an air test are suitable methods. If found to be leaking, the line should be repaired.

Recommendation #6: Graywater discharges from the family cabins should be connected to the wastewater collection system.

Recommendation #7: Lake Shakamak's hypolimnion should be treated with aluminum sulfate (alum) to help control the internal release of phosphorus from the sediments. While aeration techniques can provide numerous benefits to some lakes, phosphorus precipitation and inactivation using alum will provide the best long-term control for the least long-term maintenance and cost. The optimal time for the treatment is in the spring while soluble phosphorus still dominates in the water column. Tests should be conducted immediately prior to the application to determine the maximum, safe dose.

While other states have extensive experience with alum applications to lakes, this will be the first such treatment in Indiana. Therefore, an experienced and qualified firm should be contracted with to provide these services. We are aware of two such firms:

Sweetwater Technology Crop.
P.O. Box 3370
Palmer, PA 18043
(215) 253-9510

International Science & Technology, Inc.
11260 Roger Bacon Drive, Suite 201
Reston, VA 22090
(703) 689-0407

Information on other reliable consultants can be obtained from:

North American Lake Management Society
1000 Connecticut Ave. NW
Suite 202
Washington, D.C. 20036
(202) 466-8550

or

General Chemical Corporation
90 East Halsey Road
Parsippany, NJ 07054
(201) 515-1814

Recommendation #8: Selective harvesting of rooted aquatic macrophytes should be conducted as needed to clean areas around piers, boat launches and the beach, to provide access to cabins, and to create fishing lanes. The Division of Fish and Wildlife should be consulted before any more extensive harvesting is considered. For example, a fall harvest of dense stands could remove plant biomass that will release phosphorus and consume oxygen as it decays at the end of the growing season. This would have obvious benefits for the water quality but the potential impact on the fisheries should be discussed with Fish and Wildlife first.

Mechanical or hand harvesters can be used but in either case, the cut plant material must be removed from the lake.

Recommendation #9: The management techniques proposed here should be closely monitored both during and after implementation. This is especially true for the alum application where monthly water quality analyses should be conducted during the growing season for at least two years following treatment. The monitoring should include: dissolved oxygen and temperature profiles, total and soluble phosphorus, nitrates, ammonia, total nitrogen, pH, alkalinity and transparency.

8.2 LAKE LENAPE

While Lake Lenape's water quality is marginally better than Lake Shakamak's, the lake has similar problems. At this stage, it is best to control the continuing eutrophication of Lake Lenape by reducing inputs of sediments and nutrients to the lake. Therefore it is important to encourage the use of watershed BMTs to control soil erosion and runoff from the surrounding land. Because the lake has only one primary inlet, it is ideally suited for the construction of a sedimentation basin and wetland filter to further control sediment and nutrient inputs. Again, the DNR's Lake Enhancement Program has experience in this area and a number of consultants are currently designing these structures for Lake Enhancement project lakes. At Lake Lenape, we need to know more about the sources and quantities of sediment and nutrient inputs before the feasibility of a sedimentation basin and wetland filter can be assessed.

8.3 LAKE KICKAPOO

The youngest of the three lakes at Shakamak State Park, Lake Kickapoo also has the best water quality. The greatest threats to the continued well-being of Lake Kickapoo are the discharges of water from lakes Shakamak and Lenape, through which 70 percent of Kickapoo's watershed drains. Until water quality is improved in lakes Shakamak and Lenape, the discharges will cause Lake Kickapoo's water quality to decline gradually. Therefore, the most feasible management option for Lake Kickapoo at this time is the successful management of lakes Shakamak and Lenape.

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APPENDIX: 1985 FISH MANAGEMENT REPORT

OLD SHAKAMAK LAKE

1985 FISH MANAGEMENT REPORT

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Fisheries Biologist

FISHERIES SECTION
INDIANA DEPARTMENT OF NATURAL RESOURCES
DIVISION OF FISH AND WILDLIFE
607 State Office Building
Indianapolis, Indiana 46204

1985

OLD SHAKAMAK LAKE
Clay and Sullivan Counties

Fish Management Report
1985

INTRODUCTION

Old Shakamak Lake is a 56-acre impoundment located in Shakamak State Park near Jasonville, Indiana. The park maintains a gravel boat ramp on the lake for anglers with private boats. Fishermen may also rent boats or fish from numerous sites on the shoreline. Electric motors are permitted on Old Shakamak Lake, but outboard motors are not. Camping and picnicking facilities are located nearby in the park. There is also a public beach and several rental cabins on the lake.

Fish management work at Old Shakamak has included a series of fisheries surveys beginning in 1963. In 1973, a 14-inch minimum size limit was placed on largemouth bass. The most recent survey, conducted in 1979, found the lake's sport fishery to be in very good condition (Stillings 1981). During recent years, fisheries biologists and park personnel have received several complaints about the quality of bass fishing at Old Shakamak Lake. This survey was conducted August 14-16, 1985 to evaluate the status of the fishery, with particular emphasis on growth and reproduction of largemouth bass.

RESULTS AND DISCUSSION

Water quality parameters were normal for a small impoundment in south-central Indiana, except for alkalinity levels. Alkalinity levels were relatively low at Old Shakamak, possibly reflecting low levels of productivity. This may be partially due to the lake's forested watershed. At the time of the survey, dissolved oxygen was adequate for game fish survival to a depth of 10 feet.

Aquatic plants found at Old Shakamak included American water willow, creeping water primrose, spatterdock, duckweed, filamentous algae, white water lily, coontail, curlyleaf pondweed, eel grass, and water milfoil. Aquatic vegetation was not abundant enough to interfere with fishing except in the upper ends of coves, where spatterdock was abundant. However, this spatterdock also provided high quality habitat for fish and other aquatic animals.

Fish sampling efforts produced a total of 483 fish weighing 149 pounds. Largemouth bass was the most abundant species by number (43%), followed by bluegill (32%), redear sunfish (8%), warmouth (5%), black bullhead (4%), yellow bullhead (3%), and longear sunfish (3%). Bass also dominated the catch by weight (55%), followed by bluegill (13%), black bullhead (12%), redear sunfish (8%), yellow bullhead (5%), and warmouth (3%). The remaining species, including mosquitofish, black crappie, bluegill x redear hybrid, channel catfish, and blackstripe topminnow, were insignificant in the survey catch.

The largemouth bass sample consisted of 209 fish weighing a total of 82 pounds. Bass ranged from 3 to 17 inches in length, and 2% were legal size, 14 inches or larger. Seventy-seven percent of the bass collected were 8 to 12 inches in length. Several young-of-the-year bass were also collected, and recruitment appeared to be consistent for all year classes. Largemouth bass growth rates were average to age 2, slightly below average to age 3, and significantly below average thereafter. Weights were average for bass up to 10 inches and those larger than 14 inches, but below average for 10½ to 12 inch bass.

This data indicates that largemouth bass may be too abundant at Old Shakamak Lake. Consistent recruitment and protection from harvest have resulted in a build-up of small bass which are competing for food and space. This competition has led to declines in growth rates and condition, especially for intermediate sized fish. Growth rates are now slow enough that many bass probably succumb to natural mortality before reaching legal size. High natural mortality, coupled with heavy fishing pressure, has resulted in low abundance of legal sized fish.

The bluegill sample consisted of 152 fish weighing a total of 19 pounds. Bluegill ranged from ½ to 8½ inches in length, and 34% were harvestable size, 6 inches or larger. Bluegill weights were average for fish up to 5½ inches, above average for 6 to 7½ inch fish, and average for fish 8 inches or larger. Bluegill growth was average to age 2 and above average thereafter. Stillings (1981) reported that bluegill growth rates followed a similar pattern at Old Shakamak Lake in 1979. Rapid growth of bluegill after age 2 probably reflects low densities of adult fish.

Thirty-six redear sunfish weighing a total of 12 pounds were also collected during the survey. Redear ranged from 3½ to 10½ inches in length. Harvestable redear, those 6 inches or larger, accounted for 92% of the redear sample. Redear growth rates were slightly below average to age 2, and above average thereafter. Redear weights were average to slightly above average in comparison to redear at other area lakes.

Other species collected during the survey included warmouth, black bullhead, yellow bullhead, longear sunfish, mosquitofish, black crappie, bluegill x redear hybrid, and blackstripe topminnow. None of these species appear to be detrimental to the fishery at present. The miscellaneous sunfishes and bullheads will probably make minor contributions to the creel. It is interesting to note that this is one of the few recorded populations of mosquitofish in Indiana (Tom Flatt, fisheries supervisor, personal communication).

Only one channel catfish was collected during the survey. Channel catfish reproduction is probably limited by largemouth bass predation at Old Shakamak Lake. The low abundance of channel catfish in this collection probably reflects the intermittent nature of the previous stocking program, and possible high harvest of the most recent stocking (1983).

CONCLUSIONS AND RECOMMENDATIONS

The primary fish management goal at Old Shakamak Lake is to maintain a quality panfish fishery. The large bass population has helped achieve that goal by controlling the abundance of small panfish. Fishing opportunities for large bluegill and redear are currently very good at Old Shakamak. However, above average growth rates for adult panfish suggest that panfish numbers may be less than what the lake is capable of supporting. While high harvest of adult panfish may be partially responsible, this condition may also be due to excessive predation on small panfish. Excessive predation could result in declining densities and angler catch rates of panfish.

Secondary fish management goals at Old Shakamak Lake include satisfactory fishing opportunities for largemouth bass and channel catfish. The large increase in bass abundance has resulted in slow growth of individual bass and low numbers of legal fish. Bass fishing opportunities are essentially limited to catch-and-release at present, with an occasional legal fish available. Channel catfish fishing opportunities also appear to be limited at the present time.

To improve bass fishing at Old Shakamak Lake, it will be necessary to reduce the abundance of largemouth bass. Increasing the bag limit would not help, as most of the bass are below legal size. The 14-inch size limit should be modified to allow anglers to harvest smaller bass. Since bass recruitment appears to be excessive, a slot size limit is probably the best choice. This limit would allow anglers to harvest smaller bass, yet protect a portion of the reproductively mature population. Complete removal of the size limit is not recommended as this would require intensive monitoring to prevent collapse of the fishery.

A 12 to 15-inch slot size limit would allow anglers to harvest bass under 12 inches or over 15 inches. This slot was successfully used by Eder (1984) to improve the size structure of a bass population previously stockpiled under a 15-inch minimum limit at one Missouri impoundment. Gabelhouse (1984) applied the same slot size limit to five previously unregulated Kansas fishing lakes, and found that electrofishing catch rates for 12 to 15 inch bass increased at all five lakes. He also found the maximum number of 8-12 inch bass harvested under the limit never exceeded 26 fish per acre per year.

It is recommended that the largemouth bass size limit at Old Shakamak Lake be changed to a 12 to 15-inch slot, in conjunction with a work plan to evaluate the effects of the change. Reduced densities of bass will probably lead to some reduction in panfish growth and the average size of panfish harvested. However, the proposed change may also lead to an increase in the number of panfish harvested. While this trade-off may be considered acceptable, an evaluation will be necessary to determine if the primary fish management goal (quality panfishing) is still being met.

To improve channel catfish fishing opportunities at Old Shakamak Lake, some type of regular stocking program should be initiated. It is recommeded that channel catfish be supplementally stocked at the rate of 25 fingerlings per acre every three years. The next stocking of 1,400, 8-inch channel catfish should be done in the fall of 1986.

Aquatic weed control should be conducted periodically at Old Shakamak Lake to prevent further spread of spatterdock. Additional stands of this plant could become a nuisance to fishing activities. Since spatterdock provides good habitat for fish and other aquatic animals, it is not necessary to reduce its abundance from present levels.

LITERATURE CITED

Eder, S. 1984. Effectiveness of an imposed slot length limit of 12.0-14.9 inches on largemouth bass. North American Journal of Fisheries Management 4:469-478.

Gabelhouse, D.W., Jr. 1984. An assessment of largemouth bass slot length limits in five Kansas lakes. Federal Aid Project Number FW-9-P-3. Kansas Fish and Game Commission, Emporia, Kansas.

Stillings, G. 1981. Old Shakamak Lake fisheries management report, 1979. Indiana Department of Natural Resources, Indianapolis, Indiana. 12 pp.

Submitted by: Steven J. Andrews, Fisheries Biologist
Date: November 20, 1985

Approved by: Thomas M. Flatt
Thomas M. Flatt, Fisheries Supervisor

Approved by: William D. James
William D. James, Chief of Fisheries
Date: November 27, 1985

LAKE SURVEY REPORT FORM

State Form 24753

☐ Initial survey ☒ Re-survey ☐ Other

Lake: Old Shakamak		
County: Clay and Sullivan	Date of Survey: 8/14-16/85	
Biologist: Steven Andrews	Date of Approval: 11/27/85	

1. Quadrangle Name	R.	S.
Jasonville	8W	31,36
Township	**Nearest Town**	
9N	Jasonville	

3. ACCESSIBILITY

State Owned Public Access Site:	Privately Owned Public Access Site:	Other
Gravel boat ramp		

4. Surface Acres	Maximum Depth	Average Depth	Acre Ft.	5. Water Level	Extreme Fluctuations
56	26 Ft.	10.8 Ft.	608	552 MSL	None

6. Location of Benchmark: None

7. INLETS

Name	Location	Origin
Surface runoff		

8. OUTLET

Name	Location
Kickapoo Lake	South

9. Water Level Control: Earthen dam with concrete spillway and removable board.

10. POOL	ELEVATION *(Feet MSL)*	ACRES
TOP OF DAM		
TOP OF FLOOD CONTROL POOL		
TOP OF CONSERVATION POOL		
TOP OF MINIMUM POOL		
STREAMBED		

11. Bottom Type
- ☐ Boulder
- ☐ Gravel
- ☒ Sand
- ☒ Muck
- ☒ Clay
- ☐ Marl

12. Watershed Use: The watershed consists of 980 acres of mixed hardwoods, grasses, and some cultivated land.

13. Development of Shoreline: Boat ramp, beach, boat rental concession, and several rental cabins.

14. Previous Surveys and Investigations: Fisheries surveys 1963, 1967, 1968, 1972, 1976, and 1979.

15. SAMPLING EFFORT

ELECTROFISHING	Day Hours 0.83	Night Hours 0.75	Total Hours 1.58 D.C.	GILL NETS	Number 6	Hours varied	Total Hours 140
TRAPS	Number 4	Hours varied	Total Hours 95	SHORELINE SEINING	Number of 100 Foot Seine Hauls None		
ROTENONE	Gallons None	ppm	Acre Feet Treated				

16. PHYSICAL AND CHEMICAL CHARACTERISTICS

Color	Turbidity
Green	4 Ft. 0 Inches (SECCHI DISK)

17. TEMPERATURE

DEPTH FEET	DEGREES F	DEPTH FEET	DEGREES F
SURFACE	82.0	40	
2	81.5	42	
* 4	81.0	44	
6	79.0	46	
8	76.0	48	
10	71.0	50	
12	64.0	52	
14	59.0	54	
16	55.0	56	
18	52.5	58	
*20	51.0	60	
~~22~~ 21	Bottom 50.0	62	
24		64	
26		66	
28		68	
30		70	
32		72	
34		74	
36		76	
38		78	

18. D.O. — TOTAL ALKALINITY — PH:

DEPTH FEET	D.O ppm	ALKALINITY ppm	pH	Comments
SURFACE	13.0	34.2	9.5	Limits of thermocline: 4-20 feet.
5	12.0			
10	5.0			
15	0.0			
20	0.0	54.7	7.0	
25				
30				
35				
40				

*LIMITS OF THERMOCLINE

19. COMMON SPECIES OF AQUATIC PLANTS			
COMMON NAME	SCIENTIFIC NAME	DEPTH FOUND	PER CENT COVERED *
EMERGENT			
American water willow	Dianthera americana	0-1	<1
Creeping water primrose	Jussiaea repens	0-2	<1
Spatterdock	Nuphar advena	0-8	5
FLOATING			
Duckweed	Lemna sp.	Surface	<1
Filamentous algae		Surface	<1
White water lily	Nymphaea tuberosa	0-6	2
SUBMERGENT			
Coontail	Ceratophyllum demersum	0-8	2
Curlyleaf pondweed	Potamogeton crispus	0-2	<1
Eel grass	Vallisneria americana	0-3	<1
Water milfoil	Myriophyllum sp.	0-6	<1
-			
-			
*Percent of lake surface area covered.			

Comments

Aquatic vegetation was not a problem.

SPECIES AND RELATIVE ABUNDANCE OF FISHES COLLECTED BY NUMBER AND WEIGHT

*COMMON NAME OF FISH	NUMBER	PERCENT	LENGHT RANGE (inches)	WEIGHT (pounds)	PERCENT
Largemouth bass	209	43.3	3.0-17.1	82.31	55.4
Bluegill	152	31.5	0.5- 8.7	19.09	12.8
Redear sunfish	36	7.5	3.7-10.4	12.34	8.3
Warmouth	24	5.0	4.4- 7.3	4.63	3.1
Black bullhead	17	3.5	5.8-14.7	17.41	11.7
Yellow bullhead	14	2.9	5.7-12.2	7.17	4.8
Longear sunfish	12	2.5	2.6- 6.1	1.02	0.7
Mosquitofish	8	1.7	1.0- 1.7	**	--
Black crappie	7	1.4	2.3-11.2	2.39	1.6
Bluegill x redear sunfish hybrid	2	0.4	6.0- 6.9	0.37	0.2
Channel catfish	1	0.2	17.7	1.87	1.3
Blackstripe topminnow	1	0.2	1.5	**	---
TOTALS	483			148.60	
**Weights not available.					

*Common names of fishes recognized by the American Fisheries Society.

21. NUMBER, PERCENTAGE, WEIGHT, AND AGE OF LARGEMOUTH BASS				
TOTAL LENGTH (inches)	NUMBER	PERCENTAGE	AVE. WEIGHT (pounds)	AGE
3.0	5	2.4	0.01	0+
3.5	7	3.3	0.02	0+
4.0	8	3.8	0.03	0+
4.5	4	1.9	0.04	0+
6.0	1	0.5	0.10	1+
6.5	2	1.0	0.13	1+
7.0	8	3.8	0.15	1+
7.5	10	4.8	0.18	1+
8.0	9	4.3	0.22	1+
8.5	3	1.4	0.25	1+
9.0	12	5.7	0.31	2+
9.5	13	6.2	0.36	2+
10.0	38	18.2	0.42	2+
10.5	50	23.9	0.48	2+
11.0	24	11.5	0.53	2+ 3+
11.5	6	2.9	0.61	3+ 4+
12.0	5	2.4	0.72	3+ 4+
14.0	1	0.5	1.37	4+
14.5	1	0.5	1.43	5+
15.5	1	0.5	1.66	5+
17.0	1	0.5	2.86	7+
TOTALS	209			

SAMPLING GEAR	CATCH RATE
Electrofishing	125/hour
Gill net	2/set

21. NUMBER, PERCENTAGE, WEIGHT, AND AGE OF BLUEGILL				
TOTAL LENGTH (inches)	NUMBER	PERCENTAGE	AVE. WEIGHT (pounds)	AGE
0.5	11	7.2	*	0+
1.0	6	3.9	*	0+
1.5	4	2.6	*	0+ 1+
2.0	3	2.0	0.01	1+
2.5	9	5.9	0.01	1+
3.0	15	9.9	0.02	1+
3.5	14	9.2	0.03	1+
4.0	16	10.5	0.04	1+ 2+
4.5	6	3.9	0.06	1+ 2+
5.0	8	5.3	0.09	2+
5.5	8	5.3	0.12	2+
6.0	8	5.3	0.16	2+
6.5	7	4.6	0.21	2+ 3+
7.0	11	7.2	0.27	3+
7.5	8	5.3	0.33	3+
8.0	12	7.9	0.37	3+ 4+
8.5	6	3.9	0.46	4+ 5+
TOTAL	152			

SAMPLING GEAR	CATCH RATE
Electrofishing	70/hour
Gill net	1/set
Trap net	6/set

*Less than 0.01 pound

21. NUMBER, PERCENTAGE, WEIGHT, AND AGE OF REDEAR SUNFISH

TOTAL LENGTH (inches)	NUMBER	PERCENTAGE	AVE. WEIGHT (pounds)	AGE
3.5	1	2.8	0.03	1+
5.5	2	5.6	0.13	2+
6.0	1	2.8	0.17	2+
6.5	3	8.3	0.20	2+
7.0	10	27.8	0.25	2+
7.5	3	8.3	0.31	2+ 3+
8.0	7	19.4	0.39	3+
8.5	4	11.1	0.48	3+
9.0	2	5.6	0.53	4+
9.5	1	2.8	0.63	4+
10.0	1	2.8	0.72	4+
10.5	1	2.8	0.78	5+
TOTAL	36			

SAMPLING GEAR	CATCH RATE
Electrofishing	6/hour
Trap net	6/set

Species: Largemouth bass	Year Class	Number	Back Calculated Length I	II	III	IV	V	VI
	1984	19	4.1					
	1983	22	4.5	8.4				
	1982	6	3.8	8.8	10.8			
	1981	3	3.3	8.1	10.5	11.9		
	1980	2*	4.5	8.2	10.1	11.9	13.3	
	Average		3.9	8.4	10.7	11.9		
	Number		(50)	(31)	(9)	(3)	( )	( )

Species: Bluegill	Year Class	Number	Back Calculated Length I	II	III	IV	V	VI
	1984	19	1.0					
	1983	20	0.6	2.6				
	1982	11	0.8	3.0	6.0			
	1981	7	0.7	2.8	6.4	8.0		
	1980	1*	0.8	2.9	5.7	7.8	8.3	
	Average		0.8	2.8	6.2	8.0		
	Number		(57)	(38)	(18)	(7)	( )	( )

Species: Redear sunfish	Year Class	Number	Back Calculated Length I	II	III	IV	V	VI
	1984	1*	1.4					
	1983	11	1.1	3.7				
	1982	12	1.1	3.6	6.9			
	1981	4	1.5	3.6	6.7	8.8		
	1980	1*	1.3	4.8	8.6	9.6	10.0	
	Average		1.2	3.6	6.8	8.8		
	Number		(27)	(27)	(16)	(4)	( )	( )

Species	Year Class	Number	Back Calculated Length I	II	III	IV	V	VI
	Average							
	Number		( )	( )	( )	( )	( )	( )

*Not included in average calculations

FISH ERADICATION NONE

A. RECOMMENDED MANAGEMENT	Selective	Partial	Total	Drainage
B. PISCICIDE	Antimycin		Rotenone	
C. CONCENTRATION	(ppm) (ppb)			Gal. or ML/Acre-Foot
D. Acre - feet to be treated		E. Amount of Chemical		
F. Chemical Cost		G. Estimated Date of Project		

FISH STOCKING

A. TYPE	New Introduction	Supplemental	New Habitat
		X	

B. SPECIES	NUMBER	SIZE	DATE
Channel catfish	1,400	8 inch average	Fall 1986